TREATMENT OF ACIDIC SEEPAGES

EMPLOYING

WETLAND ECOLOGY AND MICROBIOLOGY

FINAL REPORT

BY: MARGARETE KALIN

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SUMMARY

This report is the second of the MEND project 3.11.1 entitled "Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology". The first report summarized cattail growth experiments in which cattails were used to provide organic carbon to the microbial system. It summarized the background to the experiments carried out in the first phase of the project and presented a detailed description of the test cell system in which flow can be controlled between 3-5 L/min and maximum flows of 300 L/min.

This second report provides an analysis of the seepage chemistry and hydrology which prevail in the Test Cell System. It describes the water characteristics associated with the microbial alkalinity-generation achieved in the Arumators (drums containing seepage), and characterizes organic amendment and microbial populations.

Also, it outlines the methods used in the description of the AMD chemistry of the system. These descriptions explain the natural changes which occur as the seepage emerges from the tailings dam. The conditions achieved in the Test Cell System are such that oxidation and subsequent hydrolysis of ferrous iron compounds is restricted to Cell 1. The pH of the seepage as it emerges drops by a factor of 2 to 2.5 units pH prior to entering Cell 2.

Due to these changes in the seepage water, it is necessary to determine pH and Eh in the field and to filter the water immediately following sample collection. The reproducibility

of ICP determinations which are below 1 mg/L was not considered. Higher concentrations of elements, however, showed fairly stable reproducibility with an error range of only 2% to 10%. Cation/anion balances performed on water samples from ARUMators to determine the accuracy of the analysis suggested that imbalances are associated with Fe and S. These were related to the presence of organic compounds which are smaller than 0.45 μ.

Flow control in the system affects the rate of iron precipitation. The settling characteristics of the resultant precipitate differ according to sample location in the Test Cell System. Settling rates of iron precipitate increase between the seepage ditch and Pond A. Geochemical simulations, using PHREEQE, suggested that several minerals could be formed in the seepage water. In comparison, using the same simulation program for water collected from the ARUMators, a significantly larger group of minerals can be expected to precipitate. Furthermore as the seepage passes through the Test Cell System, differences in chemical equilibria are evident which result in precipitation of different compounds due to the interaction with cell wall materials. Based on waterlevel data from the piezometer and their relationship to the water level in the cells, it was concluded that Cells 1 and 2 of the Test Cell System represented a recharge area whereas Cells 3 and 4 represented a discharge area.

In order to achieve microbial alkalinity-generation, organic amendment curtains have been placed into Test Cells 3 and 4. In August 1990, when low flow conditions had finally prevailed in the system for some time, pH and pE values indicated the onset of microbial

activity. In comparison to the open placement of organic amendment, material enclosed in drums (170 L and referred to as ARUMators) achieved complete replacement of acidity by alkalinity by the end of the summer. Complementing the field experiments, laboratory studies were carried out in which flow-through conditions are tested. Effective alkalinity-generation was maintained for 121 days at a continous flow rate of 100 ml/day for seepage from Makela. Flow-through treatment of Straw Pond seepage maintained effectiveness for only 14 days at the same rate, representing the replacement of one reactor volume. The reactors, however, recovered after failure in the flow-through condition for both seepage types.

Sulphate-reducers, iron reducers and ammonifiers are expected to be the major contributors to the alkalinity-generation and these have been isolated and purified from flow-through reactors. Alkalinity producing reactions summarized from the literature are related to carbon requirements for the reactions. It was found that for both AMD seepages (Straw Pond and Makela) the available carbohydrate greatly exceeds the theoretically required amount. Thus carbohydrate availability cannot be considered a factor inhibiting alkalinity-generation. As the conditions are defined under which the ARUM process is effective, it is now possible to address, in the field and the laboratory, those conditions which lead to failure and those which lead to optimization of the process.

SOMMAIRE

Le présent rapport est le deuxième du projet MEND 3.11.1 intitulé «Traitement des suintements acides employant l'écologie des marécages et la microbiologie». Le premier rapport résumait les expériences sur la culture des massettes au cours desquelles les massettes étaient utilisées pour fournir du carbone organique au système microbien. Il faisait le sommaire des antécédents des expériences effectuées dans la première phase du projet et présentait une description détaillée du système des cellules de test où le flux peut être contrôlé entre 3-5 L/min. et des flux maximaux de 300 L/min.

Ce deuxième rapport fournit une analyse de la chimie et de l'hydrologie des suintements qui prédominent dans le système des cellules de test. Il décrit les caractéristiques de l'eau associées à la génération microbienne d'alcalinité obtenue dans les «Arumateurs» (barils contenant le suintement), et caractérise la modification organique et les populations microbiennes.

Il expose aussi à grands traits les méthodes utilisées dans la description de la chimie AMD du système. Ces descriptions expliquent les changements naturels qui se produisent comme le suintement émerge du réservoir des résidus. Les conditions réalisées dans le système des cellules de test sont telles que l'oxydation et l'hydrolise subséquente des composés de fer ferreux se limitent à la Cellule 1. Le pH du suintement, au fur et à mesure de son émergence, baisse d'un facteur de 2 à 2,5 unités pH avant d'entrer dans la Cellule 2.

À cause de ces changements survenant dans l'eau de suintement, il est nécessaire de déterminer le pH et le Eh sur le terrain et de filtrer immédiatement l'eau après un prélèvement d'échantillons. La reproductibilité des déterminations ICP qui sont au-dessous de 1 mg/L n'a pas été prise en considération. Cependant, des concentrations plus élevées d'éléments ont montré une reproductibilité passablement stable, avec une marge d'erreur allant seulement de 2% à 10%. Les équilibres cation/anion pratiqués sur les échantillons d'eau des ARUMateurs, afin de déterminer l'exactitude de l'analyse ont semblé indiquer que les déséquilibres sont associés avec les Fe et S. Ceux-ci étaient liés à la présence de composés organiques qui sont plus petits que 0,45μ.

Le contrôle du flux dans le système influe sur la vitesse de précipitation du fer. Les caractéristiques de sédimentation du précipité qui en résulte diffèrent selon l'emplacement de l'échantillon dans le système des cellules de test. Les vitesses de sédimentation des précipités de fer augmentent entre le fossé de suintement et l'Étang A. Les simulations géochimiques, utilisant PHREEQE, ont semblé indiquer que plusieurs minéraux pouvaient se former dans l'eau de suintement. En comparaison, en utilisant le même programme de simulation pour l'eau prélevée des ARUMateurs, on peut s'attendre à la précipitation d'un groupe considérablement plus grand de minéraux. De plus, comme le suintement passe à travers le système des cellules de test, les différences dans l'équilibre chimique sont évidentes, entraînant ainsi la précipitation de différents composés, par suite de l'interaction avec les matériaux des parois des cellules. En se fondant sur les données

du niveau d'eau provenant du piézomètre et leur rapport au niveau d'eau des cellules, on a conclu que les Cellules 1 et 2 du système de cellules de test représentaient une aire de recharge, alors que les Cellules 3 et 4 représentaient une aire de décharge.

Afin d'obtenir la génération d'alcalinité microbienne, des rideaux de modification organique ont été placés dans les Cellules de test 3 et 4. En août 1990, lorsque des conditions de flux bas avaient finalement dominé dans le système, pendant un certain temps, les valeurs de pH et de pE ont indiqué le commencement de l'activité microbienne. En comparaison du placement ouvert de la modification organique, les matériaux enfermés dans des barils (de 170 L et appelés ARUMateurs) réalisèrent le remplacement complet de l'acidité par l'alcalinité, avant la fin de l'été. En complément des expériences sur le terrain, des études en laboratoire ont été effectuées où les conditions de flux traversant sont testés. La génération d'alcalinité effective a été maintenue pendant 121 jours à une vitesse de flux continu de 100 mL/ par jour pour le suintement provenant de Makela. Le traitement de flux traversant du suintement de Straw Pond n'a maintenu son efficacité que pendant 14 jours à la même vitesse, représentant le remplacement du volume d'un réacteur. Cependant, les réacteurs ont recommencé à fonctionner après leur panne en situation de flux traversant, pour les deux types de suintement.

On s'attend à ce que les réducteurs de sulphate, les réducteurs de fer et les ammonificateurs soient les principaux contributeurs à la génération d'alcalinité et ceux-ci ont été isolés des réacteurs de flux traversant et purifiés. Les réactions productrices d'alcalinité résumées à partir de la documentation, sont liées aux exigences carbonique des réactions. Il a été constaté que pour les deux suintements AMD (Straw Pond et Makela), l'hydrate de carbone disponible dépasse grandement la quantité théoriquement nécessaire. Ainsi, on ne peut pas considérer la disponibilité de l'hydrate de carbone comme un facteur inhibant la génération d'alcalinité. Comme les conditions d'efficacité du procédé ARUM sont définies, il est possible de s'occuper maintenant, sur le terrain et en laboratoire, des conditions qui entraînent une panne et des conditions qui optimisent le procédé.

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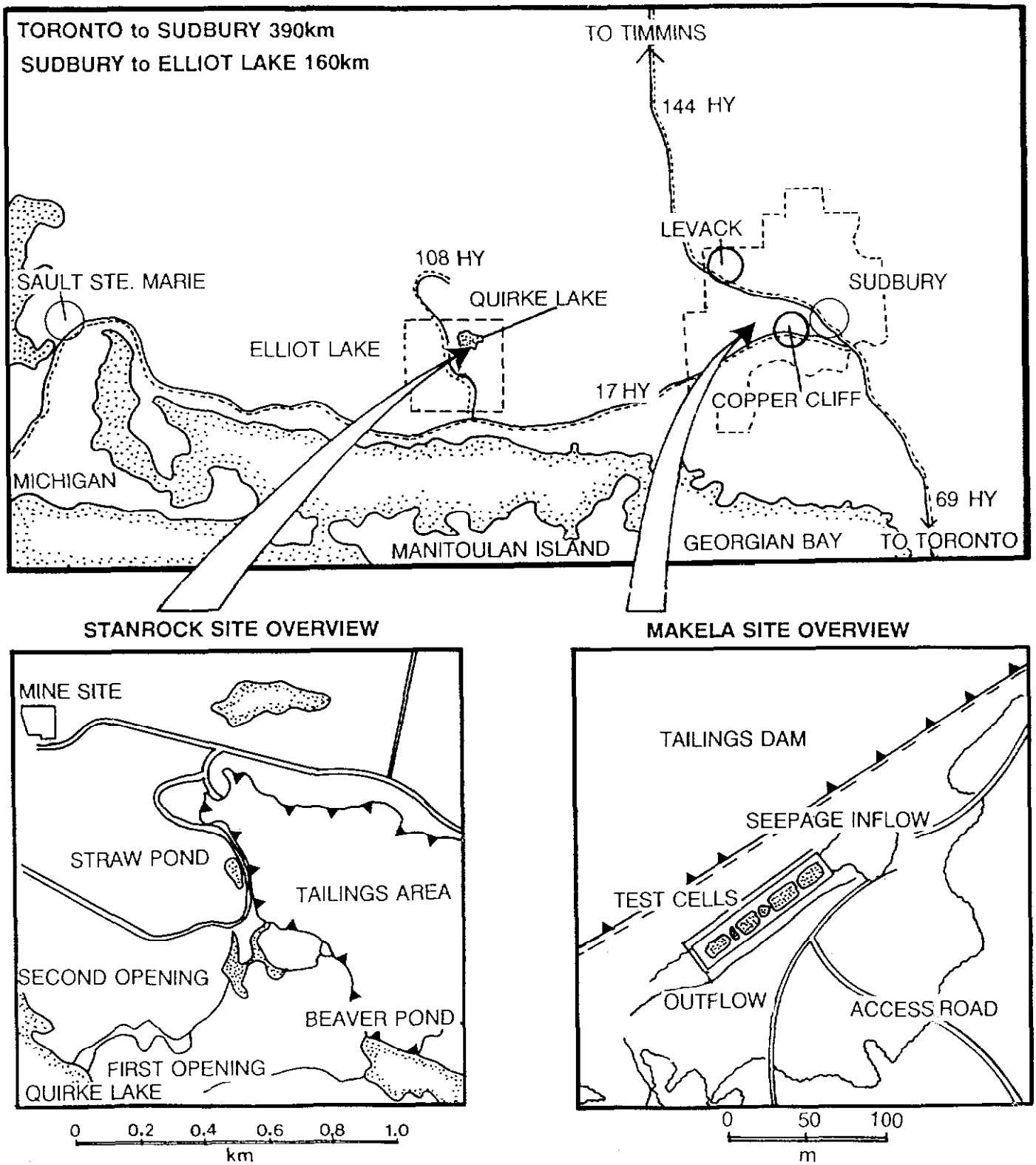
1.0. INTRODUCTION

The main objective of the Mend project, "Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology", is to identify those conditions in which AMD seepages could be ameliorated microbially. This would provide a cost-effective, alternative-treatment technology for conditions where conventional treatment is not feasible. Such conditions are frequently encountered during decommissioning and at abandoned mining operations.

The project encompasses field tests in two locations in Central Ontario which produce acid mine drainage with different characteristics. One of the locations where testing is carried out is a seepage from the Denison Stanrock inactive tailings area, located in Elliot Lake. Here, seepage from the Stanrock uranium tailings collects at one location below a dam in an area referred to as Straw Pond. The second location is one of the seepage stations at the INCO Copper Cliff tailings in Sudbury, Ontario, referred to as Makela, where a Test Cell System was constructed in 1989 and 1990 (Map 1).

The purpose behind the construction of the Test Cell System was to control the AMD seepage flow between 2 and 5 L/min, with a maximum flow of 200 L/min. With controlled flow, conditions favourable to microbial alkalinity-generation could be tested. The test cell construction and the final configuration were described in the first report (Kalin 1990). Organic amendments were added to the test cells as amendment curtains (i.e.

Map 1: Location of Project Field Test Sites



developed to describe the test cell chemistry. The analytical reproducibility and chemical dynamics of the system are presented in Section 2. The physical and chemical conditions which prevail in the Test Cell System and the controlling factors affecting water quality and iron precipitation are given in Section 3. Microbial alkalinity-generation in laboratory flow-through reactors and in batch field ARUMators is discussed in section 4. Also discussed in section 4 is the precipitation which is expected to take place once the appropriate redox conditions are established. A summary of the conclusions which can be derived to date from the project is provided in point form in Section 5.

2.0 METHODS FOR THE DESCRIPTION OF AMD

Acid mine drainage emerging from a tailings dam is a chemically dynamic solution. It was therefore necessary to evaluate sampling and analytical techniques so that changes brought about by the ARUM process and naturally-occurring processes could be distinguished. It was suspected that measurements made in the field and those made later in the laboratory differed. Laboratory-based measurements would therefore lead to an inappropriate understanding of the field systems. Thus, a systematic study was carried out during the summer of l990 to compare laboratory and field measurements.

2.1. Natural Changes in AMD Tailings Seepages

Alkalinity of natural water samples normally reflects the presence of carbonate ions and minor amounts of hydroxide, silicate, borate, ammonium, HS^- ions, and organic ligands. Acidity of water samples reflects the presence of Fe, Al and other metal ions and, at low pH values, the presence of H^+, H_2CO_3, H_2S, and H_2SO_4. It is often impossible to distinguish the individual contributions to acidity and alkalinity, due to the range of possible contributors.

Figures 1A to 1F show the result of a number of titration tests for acidity that were carried out on samples from: (1) various sample points in the Test Cell System, collected in July

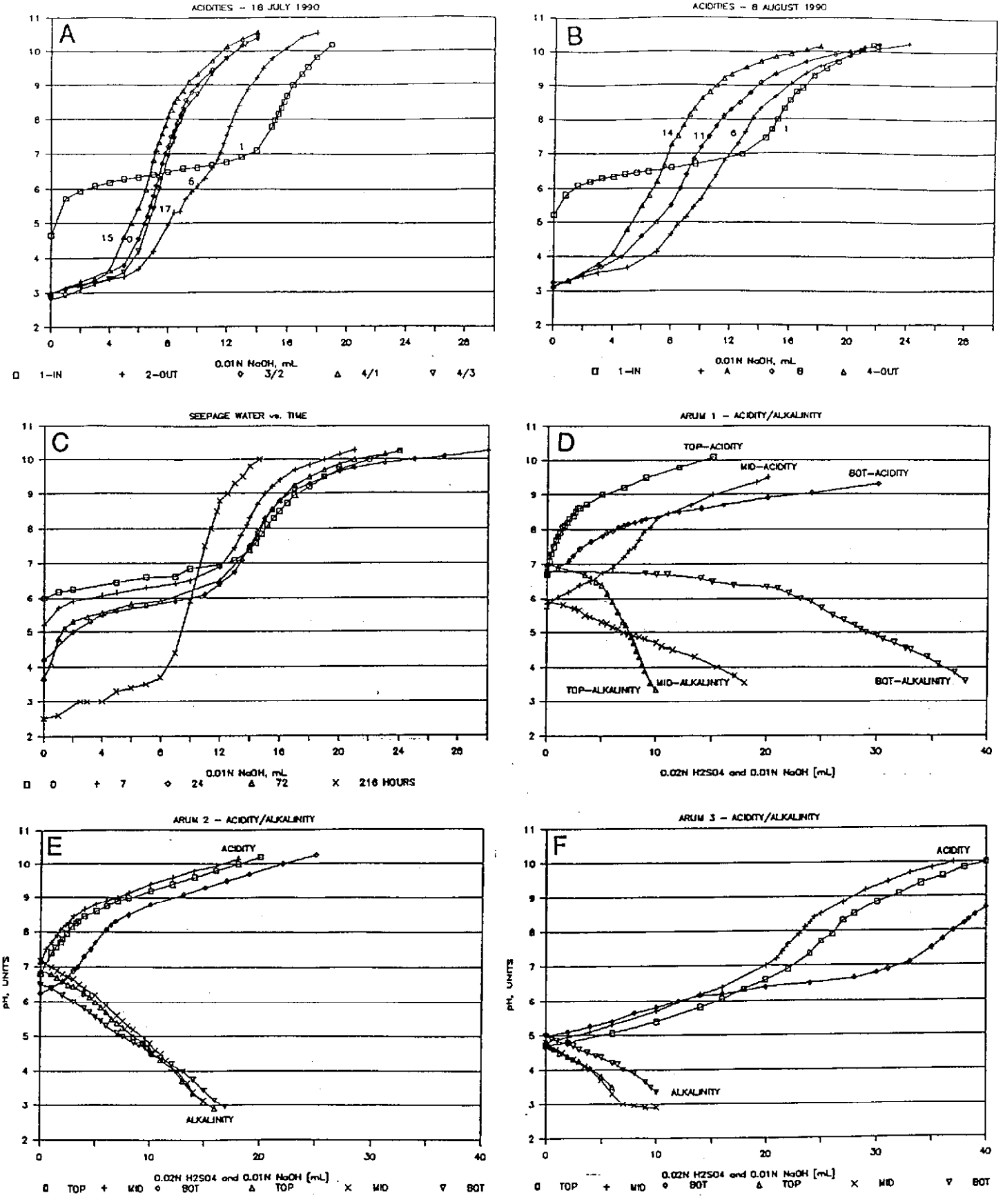


Figure 1: Acidities in Makela water

A,B - Sampling location at different dates
C - Titration in laboratory
D,E,F - Arumator 1, 2, 3

sandwiched between two plastic snow fences). Selection of organic material was based on earlier experiments involving alkalinity-generation in field enclosures (cages) exposed to different types of AMD (Kalin 1990). In these experiments, cage amendment and AMD water was brought into the laboratory and placed in glass jars where pH was monitored for several months. In other experiments, microbial ecology was studied using flow-through reactors to determine ARUM (Acid Reduction Using Microbiology) ecosystem performance criteria.

Long-term performance of ARUM alkalinity-generation depends on a continuous source of carbon and nutrients for bacterial populations. If, however, wetland vegetation is rooted in the organic amendment layer, the substrate for microbial alkalinity-generation will serve as a nutrient source to wetland vegetation, competing for the supply with the microbial community.

As a possible carbon source, cattail (*Typha latifolia*) growth has been studied under highly acidic conditions for the last several years. Floating structures which support cattail populations have been designed and tested. Methods have also been developed to successfully establish cattail populations on acidic tailings.

A further component of the project was to define those conditions under which iron precipitation could be optimized in the Test Cell System. All of these components were described in the first report, which forms the background to the present report. This is the second report on the Mend project 3.11.1, and presents methods which were

and August 1990; (2) the seep, at increasing time delays after collection; and tests for both acidity and alkalinity of samples from the three ARUMators. Raw data for the graphs are given in data Appendix 1, as table D-1 to D-4 .

The acidity curves in Figures 1A and 1B show the progressive changes AMD water undergoes in the treatment system between inflow and outflow, changing from primarily Fe^{2+} acidity to primarily H^+ and Fe^{3+} acidity. The differences between the two figures reflect (a) differences in the original [Fe] and pH of the samples, and (b) the 'age' of the samples.

In Figure 1C, the flattish first part of the curve for 0 hours represents Fe^{2+} hydrolysis. The progressive changes in shape shown by later curves reflect the effects of (1) oxidation of Fe^{2+} to Fe^{3+}, and (2) hydrolysis of Fe^{3+} to $Fe(OH)_3$, which lowers the pH and changes the initial bend of the curves. The flattish first part of the curve for 216 hours reflects Fe^{3+} hydrolysis.

Given these changes in AMD water as it emerges from the tailings dam and is exposed to the air in the test tells, it is evident that titrations have to be carried out on site and not delayed until samples are transported to the lab. To illustrate the magnitude and type of changes which occur between field and laboratory, measurements of pH, Eh, alkalinity and acidity were made on the same samples in the field and the laboratory. Samples from three different sources with different characteristics were used: water from ARUMators (high organic content), surface water from the test cell with high dissolved

ferric/ferrous content, and ground water from piezometers (disequilibrium under ambient atmospheric conditions).

The results of the comparison are plotted in Figures 2,3,4 and 5. The laboratory measurements show that the pH of ARUMator samples increases, the pH of the surface samples decreases, and pH both decreases and increases in ground water samples (Fig. 2). The pH increase in ARUMator samples is most likely due to continuing biological activity and/or loss of carbon dioxide. The decrease in pH of the surface water points to further oxidation and/or hydrolysis of the iron compounds, whereas the positive changes in the ground water are caused by degassing of the sample during transport. Partial pressures of dissolved gases (in particular CO_2) in ground water are at disequilibrium under atmospheric conditions. The drop in pH of ground water samples P-7 & P-5, which contain considerable amounts of iron, is the result of oxidation/hydrolysis.

Laboratory measurements of Eh show drastic differences in comparison to the field (Fig. 3). All laboratory measurements show significant Eh increases, with the exception of a few ground water samples. The magnitude of the change between field and laboratory is sufficiently large that totally different results would be obtained from geochemical mineral precipitation computer simulation runs (see Section 3.2.3).

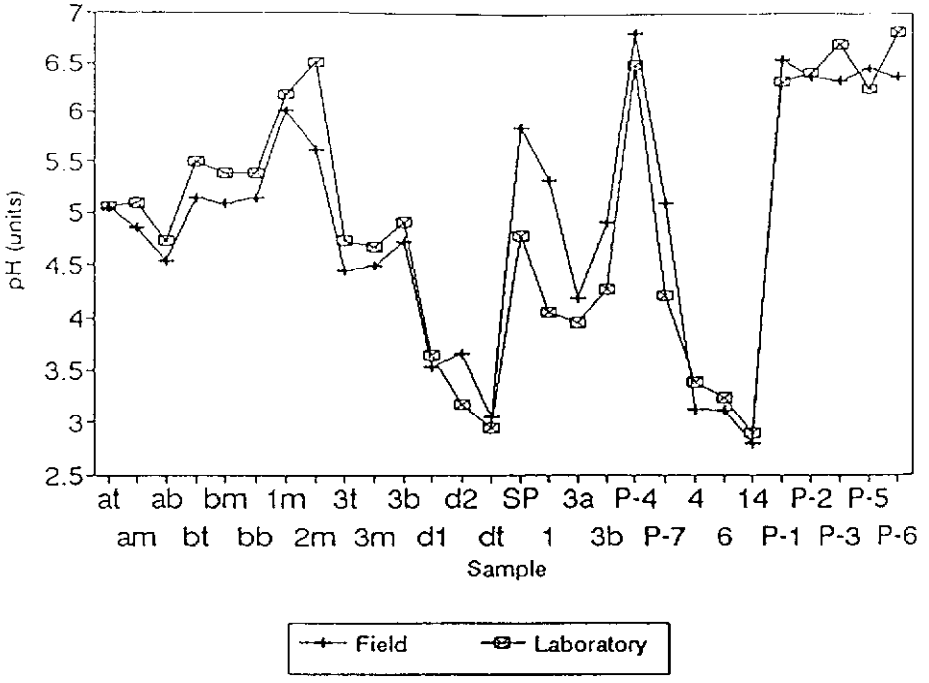


Figure 2: pH: Field and Laboratory

Codes from left to right refer to: a,b = ARUMators A and B; t=top, m=mid, b=bottom 1,2,3 = ARUMators 1,2,3. The rest of the codes refer to sampling stations at Makela and are shown in Schematics 1 and 2.

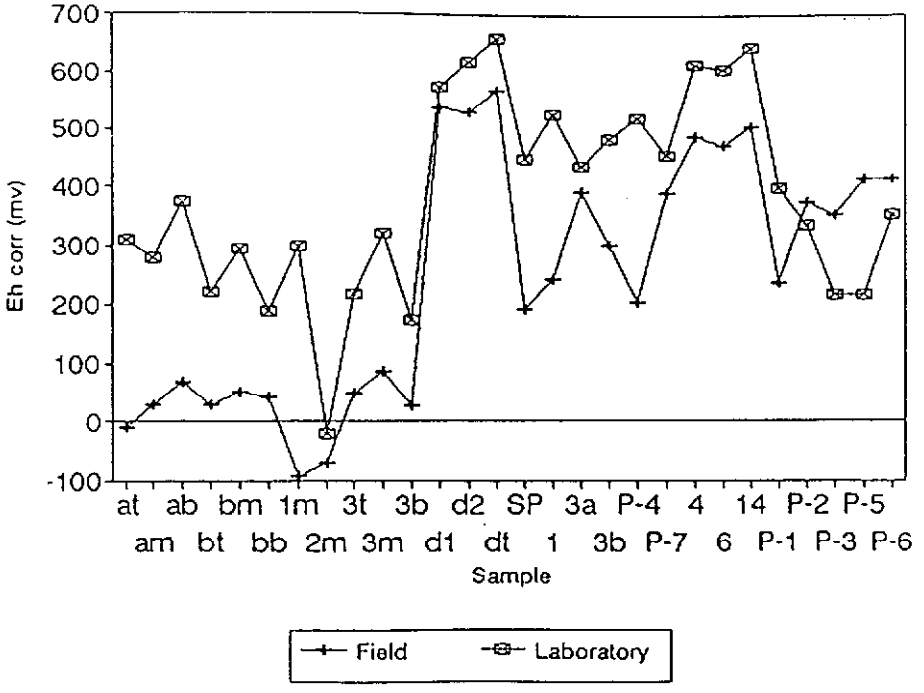


Figure 3: Eh: Field and Laboratory

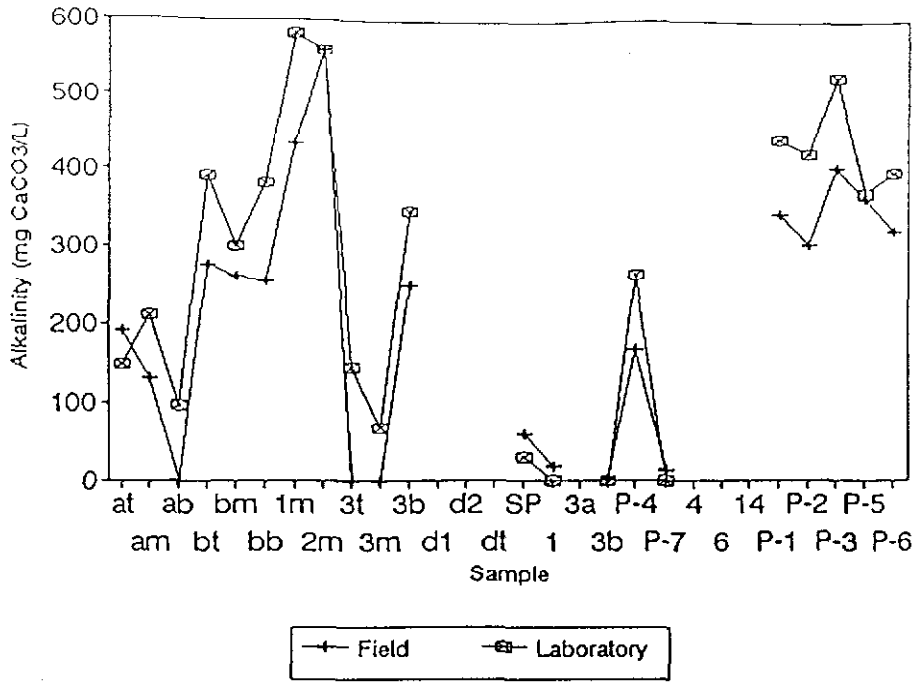


Figure 4: Alkalinity: Field and Laboratory

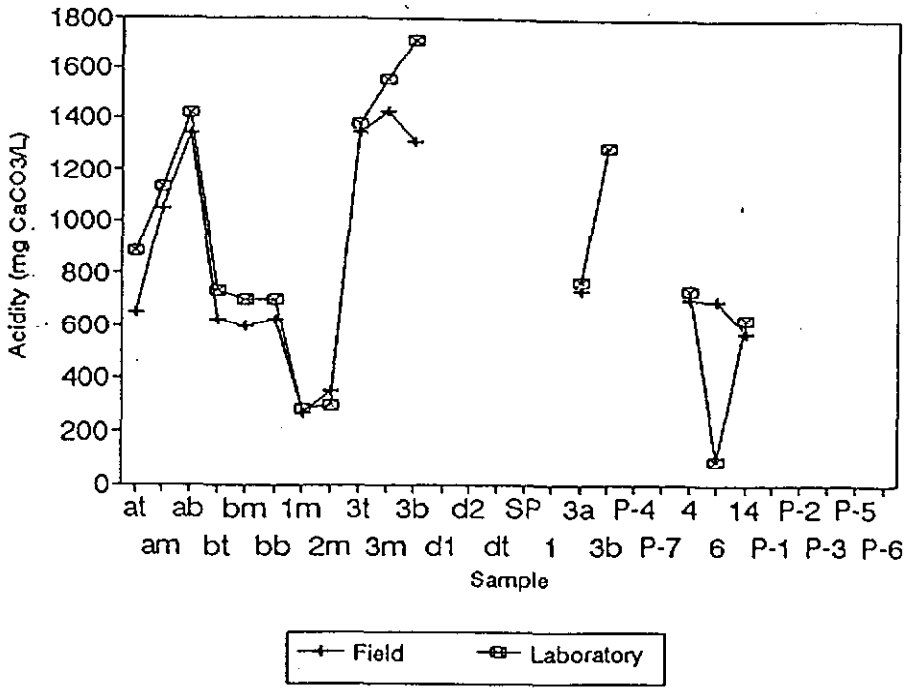


Figure 5: Acidity: Field and Laboratory

Differences between field and laboratory alkalinity and acidity measurements also reflect the dynamics of water samples (Figs. 4 and 5). Alkalinities in the field are lower than those measured in the lab, with the exception of seepage water (SP,1). Likewise, field acidities are lower than corresponding laboratory numbers, with the sole exception of STN 6.

These results suggest that the results of the analysis of the water not filtered and acidified immediately in the field, would not appropriately reflect conditions which prevail in the amendments or in the Test Cell System.

2.2. Reproducibility and Analytical Errors

Water samples from the Test Cell System and from the ARUMators are filtered through 0.45 μm membrane filters immediately after collection in the field. After filtration the water is immediately acidified with concentrated nitric acid. Elemental concentrations are determined, using ICP, by Assayers Ontario. The detection limits of the multi-elemental analysis for water, solid samples and filter papers are given in Table 1.

The reproducibility of the analytical technique has been evaluated by subjecting the sample to repeated analysis. The results of the reproducibility tests are presented in Table 2.

ELEMENT	WATER SAMPLE [mg/L]	SOLID SAMPLE [ppm]	FILTER PAPER SAMPLE [micrograms]
Ag	< .01	< .1	< .1
Al	< .01		
As	< .01	< 10	< .1
B	< .01	< .01 % or < 10	< .1
Ba	< .01	< 10	< .1
Be	< .01	< 10	< .1
Bi	< .01	< 10	< .1
C	< .01		
Ca	< .01		
Cd	< .01	< 10	< .1
Ce	< .01	< 10	< .1
Co	< .01	< 10	< .1
Cr	< .01	< 10	< .1
Cu	< .01	< 10	< .1
Fe	< .01		
Hg	< .01		
K	< 1 or given value		
La	< .01	< 10	< .1
Mg	< .01		
Mn	< .01		
Mo	< .01	< 10	< .1
Na	< .01		
Nb	< .01	< 10	< .1
Ni	< .01	< 10	< .1
P	< .01		
Pb	< .01	< 10	< .1
S	< .01	< .01 % or < 10	< .1
Sb	< .01	< 10	< .1
Se	< .01	< 10	< .1
Si	< .01		
Sn	< .01	< 10	< .1
Sr	< .01	< 10	< .1
Te	< .01	< 10	< .1
Th	< .01	< 10	< .1
Ti	< .01		
U	< .01	< 10	< .1
V	< .01	< 10	< .1
W	< .01	< 10	< .1
Y	< .01	< 10	< .1
Zn	< .01	< 10	< .1
Zr	< .01	< 10	< .1

Table 1: Detection limits of ICP multi-elemental analysis

Table 2 (Part 1 of 3)

SAMPLE DATE	6-Jul-90	6-Jul-90		6-Jul-90	6-Jul-90		6-Jul-90	6-Jul-90	
SAMPLE VOL.	250	100		250	100		250	100	
ASSAY. CODE	1876	1876		1877	1877		1878	1878	
SAMPL.LOCAT.	DENISON Sed Water #1	DENISON Sed Water #1	DENISON Sed Water #1	DENISON Sed Water #2	DENISON Sed Water #2	DENISON Sed Water #2	DENISON Treatment	DENISON Treatment	DENISON Treatment
	1 check	2 check	differ	1 check	2 check	differ	1 check	2 check	differ
UNITS	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Al	5.3	5.3	0.0	12	12	0.0	1.3	1.3	0.0
Ca	208	217	4.3	359	372	3.6	692	711	2.7
Cd	1	1	0.0	1	1	0.0	1	22	2100.0
Co	1	1	0.0	1.1	1	-9.1	1	1	0.0
Cu	1	1	0.0	1	1	0.0	1	1	0.0
Fe	346	336	-2.9	101	90	-10.9	205	189	-7.8
K	23	27	17.4	13	16	23.1	17	19	11.8
La	1	1	0.0	2.2	2.3	4.5	1	1	0.0
Mg	36	30	-16.7	76	70	-7.9	158	146	-7.6
Mn	15	13	-13.3	46	40	-13.0	19	17	-10.5
Na	14	12	-14.3	23	24	4.3	73	79	8.2
Ni	1	1	0.0	1	1	0.0	1	1	0.0
P	1	1.2	20.0	1	1	0.0	1	1	0.0
Pb	1.1	1	-9.1	1	1	0.0	1	1	0.0
S	456	455	-0.2	492	498	1.2	905	913	0.9
Si	22	21	-4.5	15	17	13.3	11	11	0.0
Sr	1	1	0.0	1.5	1.6	6.7	1.5	1.7	13.3
Y	1	1	0.0	1	1	0.0	1	1	0.0
Zn	1	1	0.0	1.2	1.2	0.0	1	1	0.0
SAMPLE DATE	7-Jul-90	7-Jul-90		7-Jul-90	7-Jul-90		7-Jul-90	7-Jul-90	
SAMPLE VOL.	250	100		250	100		250	100	
ASSAY. CODE	1863	1863		1864	1864		1865	1865	
SAMPL.LOCAT.	Denison Arum A Bottom	DENISON Arum A Bottom	DENISON Arum A Bottom	DENISON Arum A Middle	DENISON Arum A Middle	DENISON Arum A Middle	DENISON Arum A Top	DENISON Arum A Top	DENISON Arum A Top
	1 check	2 check	differ	1 check	2 check	differ	1 check	2 check	differ
UNITS	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Al	7.2	6.6	-8.3	3.8	3.2	-15.8	2.7	2.6	-3.7
Ca	207	202	-2.4	197	178	-9.6	166	194	16.9
Cd	1	1	0.0	1	1	0.0	1	1	0.0
Co	1	1	0.0	1	1	0.0	1	1	0.0
Cu	1	1	0.0	1	1	0.0	1	1	0.0
Fe	425	415	-2.4	422	401	-5.0	325	339	4.3
K	52	51	-1.9	53	60	13.2	49	53	8.2
La	1	1	0.0	1	1	0.0	1	1	0.0
Mg	19	14	-26.3	17	13	-23.5	15	13	-13.3
Mn	4.1	3.1	-24.4	4.1	2.8	-31.7	3.3	2.9	-12.1
Na	11	8.7	-20.9	12	11	-8.3	12	10	-16.7
Ni	2.3	2.2	-4.3	1	1	0.0	1	1	0.0
P	6.1	5.7	-6.6	6.4	5.9	-7.8	3.3	3.6	9.1
Pb	1	1	0.0	1	1	0.0	1	1	0.0
S	325	313	-3.7	303	290	-4.3	250	260	4.0
Si	12	11	-8.3	12	10	-16.7	11	11	0.0
Sr	1	1	0.0	1	1	0.0	1	1	0.0
Y	1	1	0.0	1	1	0.0	1	1	0.0
Zn	1	1	0.0	1	1	0.0	1	1	0.0

Table 2: Reproducibility of ICP analysis

Table 2 (Part 2 of 3)

SAMPLE DATE	7-Jul-90	7-Jul-90		7-Jul-90	7-Jul-90		7-Jul-90	7-Jul-90	
SAMPLE VOL.	250	100		250	100		250	100	
ASSAY. CODE	1866	1866		1867	1867		1868	1868	
SAMPL.LOCAT.	DENISON Arum B Bottom 1 check	DENISON Arum B Bottom 2 check	DENISON Arum B Bottom differ	DENISON Arum B Middle 1 check	DENISON Arum B Middle 2 check	DENISON Arum B Middle differ	DENISON Arum B Top 1 check	DENISON Arum B Top 2 check	DENISON Arum B Top differ
PROC. CODE	FA	FA	%	FA	FA	%	FA	FA	%
Al	1.5	1.5	0.0	1.3	1.3	0.0	1.4	1.4	0.0
Ca	109	119	9.2	109	116	6.4	106	118	11.3
Cd	1	1	0.0	1	1	0.0	1	1	0.0
Co	1	1	0.0	1	1	0.0	1	1	0.0
Cu	1	1	0.0	1	1	0.0	1	1	0.0
Fe	163	159	-2.5	160	153	-4.4	158	158	0.0
K	45	47	4.4	50	50	0.0	43	45	4.7
La	1	1	0.0	1	1	0.0	1	1	0.0
Mg	12	10	-16.7	12	10	-16.7	12	10	-16.7
Mn	3.2	2.7	-15.6	3.1	2.5	-19.4	3.1	2.6	-16.1
Na	9.4	8.3	-11.7	8.9	7.6	-14.6	8.5	7.4	-12.9
Ni	1	1	0.0	1	1	0.0	1	1	0.0
P	6.1	6.2	1.6	5.4	5.4	0.0	5.4	5.6	3.7
Pb	1	1	0.0	1	1	0.0	1	1	0.0
S	10	5.8	-42.0	15	12	-20.0	9.4	7.7	-18.1
Si	11	10	-9.1	11	10	-9.1	10	10	0.0
Sr	1	1	0.0	1	1	0.0	1	1	0.0
Y	1	1	0.0	1	1	0.0	1	1	0.0
Zn	1	1	0.0	1	1	0.0	1	1	0.0

SAMPLE DATE	21-Aug-90	21-Aug-90		21-Aug-90	21-Aug-90		21-Aug-90	21-Aug-90	
SAMPLE VOL.	100	100		100	100		100	100	
ASSAY. CODE	2071	2071		2073	2073		2074	2074	
SAMPL.LOCAT.	DENISON SP Weir Surface 1 check	DENISON SP Weir Surface 2 check	DENISON SP Weir Surface differ	DENISON S Pond Stn E Surface	DENISON SP Stn E Surface 2 check	DENISON SP Stn E Surface differ	DENISON SP Arum A Short Pipe 1 check	DENISON SP Arum A Short Pipe 2 check	DENISON SP Arum A Short Pipe differ
PROC. CODE	FA	FA	%	FA	FA	%	FA	FA	%
Al	73	67	-8.2	62	57	-8.1	1	1.1	10.0
Ca	278	271	-2.5	236	226	-4.2	102	97	-4.9
Cd	1	1	0.0	1	1	0.0	1	1	0.0
Co	1.1	1.1	0.0	1	1	0.0	1	1	0.0
Cu	1	1	0.0	1	1	0.0	1	1	0.0
Fe	685	702	2.5	464	462	-0.4	78	77	-1.3
K	4.1	4.6	12.2	2.5	2.3	-8.0	47	49	4.3
La	1.4	1.3	-7.1	1.3	1.2	-7.7	1	1	0.0
Mg	60	57	-5.0	50	46	-8.0	11	11	0.0
Mn	8.4	8.1	-3.6	7.2	6.7	-6.9	2.4	2.2	-8.3
Na	22	20	-9.1	18	16	-11.1	11	10	-9.1
Ni	1	1	0.0	1	1	0.0	1	1	0.0
P	2.4	2.5	4.2	1.7	1.6	-5.9	2.1	2.2	4.8
Pb	1	1	0.0	1	1	0.0	1	1	0.0
S	1187	1177	-0.8	952	920	-3.4	4.1	4.1	0.0
Si	18	17	-5.6	13	12	-7.7	13	12	-7.7
Sr	1.1	1.1	0.0	1	1	0.0	1	1	0.0
Y	2.9	2.6	-10.3	2.4	2.1	-12.5	1	1	0.0
Zn	2.8	2.8	0.0	2.1	2.1	0.0	1	1	0.0

Table 2 (Part 3 of 3)

SAMPLE DATE	21-Aug-90	21-Aug-90		21-Aug-90	21-Aug-90		21-Aug-90	21-Aug-90	
SAMPLE VOL.	100	100		100	100		100	100	
ASSAY. CODE	2075	2075		2076	2076		2077	2077	
SAMPL.LOCAT.	DENISON SP Arum A Long Pipe 1 check	DENISON SP Arum A Long Pipe 2 check	DENISON SP Arum A Long Pipe differ	DENISON SP Arum B Short Pipe 1 check	DENISON SP Arum B Short Pipe 2 check	DENISON SP Arum B Short Pipe differ	DENISON SP Arum B Long Pipe 2 check	DENISON SP Arum B Long Pipe 2 check	DENISON SP Arum B Long Pipe differ
PROC. CODE	FA	FA	%	FA	FA	%	FA	FA	%
Al	6.2	6.1	-1.6	1	1	0.0	1	1	0.0
Ca	126	117	-7.1	113	97	-14.2	98	86	-12.2
Cd	1	1	0.0	1	1	0.0	1	1	0.0
Co	1	1	0.0	1	1	0.0	1	1	0.0
Cu	1	1	0.0	1	1	0.0	1	1	0.0
Fe	148	144	-2.7	247	224	-9.3	14	130	828.6
K	38	40	5.3	46	45	-2.2	43	42	-2.3
La	1	1	0.0	1	1	0.0	1	1	0.0
Mg	12	12	0.0	13	12	-7.7	11	10	-9.1
Mn	2.4	2.2	-8.3	4.3	3.7	-14.0	3.1	2.7	-12.9
Na	8.7	8.1	-6.9	9.1	8.2	-9.9	7.8	7.1	-9.0
Ni	1	1	0.0	1	1	0.0	1	1	0.0
P	1.4	1.5	7.1	2.4	2.3	-4.2	1.7	1.6	-5.9
Pb	1	1	0.0	1	1	0.0	1	1	0.0
S	166	160	-3.6	5.7	5.2	-8.8	4.4	3.9	-11.4
Si	10	9.7	-3.0	16	14	-12.5	12	11	-8.3
Sr	1	1	0.0	1	1	0.0	1	1	0.0
Y	1	1	0.0	1	1	0.0	1	1	0.0
Zn	1	1	0.0	1	1	0.0	1	1	0.0

The samples from Denison Straw Pond were selected arbitrarily for discussions of data reproducibility, as these samples were frequently reanalysed. Elements with concentrations below 1 mg/L were not taken into account when percentage differences were calculated. To consider the analytical chemistry at these trace levels would be highly inappropriate at this stage in the process development. Therefore, all concentrations below 1 mg/L were not included in this examination of reproducibility.The percentage errors presented in Table 2 were small, and it was concluded that the reproducibility of the semi-quantitative analysis with ICP was reasonable, with an error range from 2 to 10%. For the elements Mg, Mn, Na and S there was a maximum error of 30% which should be considered when interpreting data.

Analytical results can also be checked for their reliability by calculating a complete anion/cation balance. Using the complete water chemistry data set from Copper Cliff and Denison, it was noted that the cation/anion balance was in some cases very good and in other cases poor (Data Tables B1 to B4 , C1 to C2 and Denison data in Appendix 1). Initially it appeared that the large errors were occurring at random. This was considered unacceptable and relationships between the major elements were investigated. It was found that the highest positive errors were found for samples with low [S], where [Fe] was larger to much larger than [S]. Such excesses of [Fe] over [S] are not possible if all Fe is derived from oxidation of sulfide minerals, if Fe is lost only through precipitation of ferric-hydroxide, jarosite or pyrite, and if S is lost only through precipitation of gypsum, jarosite or metal sulfides. Although iron was added to the ARUMators, the large error in the iron balance cannot be explained based on inorganic mass balance equilibria.

Some samples were selected for refiltration and re-analyzed. The pH in all the filtered/acidified samples was below pH 1. The results obtained after the second filtration are presented in Table 3. The filtered/acidified samples were processed in the field, collected in October 1990 and stored in the refrigerator until December 1990, at which time they went into long-term storage at room temperature until re-analysis in February 1991. The re-analyses demonstrate quite clearly that reduction in the concentrations of major elements has occurred.

All samples with a relatively high error had, after retrieval from the storage room, a cloudy yellow/green precipitate and a strongly organic odour. The 0.45 μm filters from the refiltered set of samples also showed gradations in precipitate collected, associated with the percentage error in the ion balance from the first analytical run (Plate 1). The darkest filter corresponded with the greatest error.

SAMPLE DATE	4-Oct-90	4-Oct-90	4-Oct-90			
SAMPLE VOLUM	100	100	100			
ASSAYERS CODE	2203	2469	2471			
SAMPLING LOCA	Makela Arum#3 Bottom 1 check	Makela Arum#3 Bottom 2 check	Makela Arum#3 Bottom refil	Makela Arum#3 Bottom differ	Makela Arum#3 Bottom differ	Makela Arum# Bottom differ
Units	mg/L	mg/L	mg/L	%	%	%
	1	2	3	2-1	3-1	3-2
B	0.01	1.1	1.1	10900.0	10900.0	0.0
Ca	492	402	332	-18.3	-32.5	-17.4
Fe	294	327	275	11.2	-6.5	-15.9
K	166	293	248	76.5	49.4	-15.4
Mg	210	284	249	35.2	18.6	-12.3
Mn	22	26	22	18.2	0.0	-15.4
Na	149	152	137	2.0	-8.1	-9.9
Ni	0.6	1.1	0.8	83.3	33.3	-27.3
P	12	15	12	25.0	0.0	-20.0
S	658	774	684	17.6	4.0	-11.6
Si	20	24	20	20.0	0.0	-16.7
Sr	2.9	1.5	1.3	-48.3	-55.2	-13.3
SAMPLE DATE	4-Oct-90	4-Oct-90	4-Oct-90			
SAMPLE VOLUM	100	100	100			
ASSAYERS CODE	2204	2470	2472			
SAMPLING LOCA	Makela Arum#3 Homo 1 check	Makela Arum#3 Homo 2 check	Makela Arum#3 Homo refil	Makela Arum#3 Homo differ	Makela Arum#3 Homo differ	Makela Arum# Homo differ
Units	mg/L	mg/L	mg/L	%	%	%
	4	5	6	5-4	6-4	6-5
B	0.01	0.9	0.7	8900.0	6900.0	-22.2
Ca	497	358	310	-28.0	-37.6	-13.4
Fe	244	244	213	0.0	-12.7	-12.7
K	169	266	226	57.4	33.7	-15.0
Mg	207	264	230	27.5	11.1	-12.9
Mn	22	23	20	4.5	-9.1	-13.0
Na	146	143	125	-2.1	-14.4	-12.6
Ni	3.1	4.1	3.5	32.3	12.9	-14.6
P	12	13	11	8.3	-8.3	-15.4
S	685	727	645	6.1	-5.8	-11.3
Si	20	22	18	10.0	-10.0	-18.2
Sr	2.9	1.4	1.2	-51.7	-58.6	-14.3

Table 3: Organic precipitation in filtered acidified samples

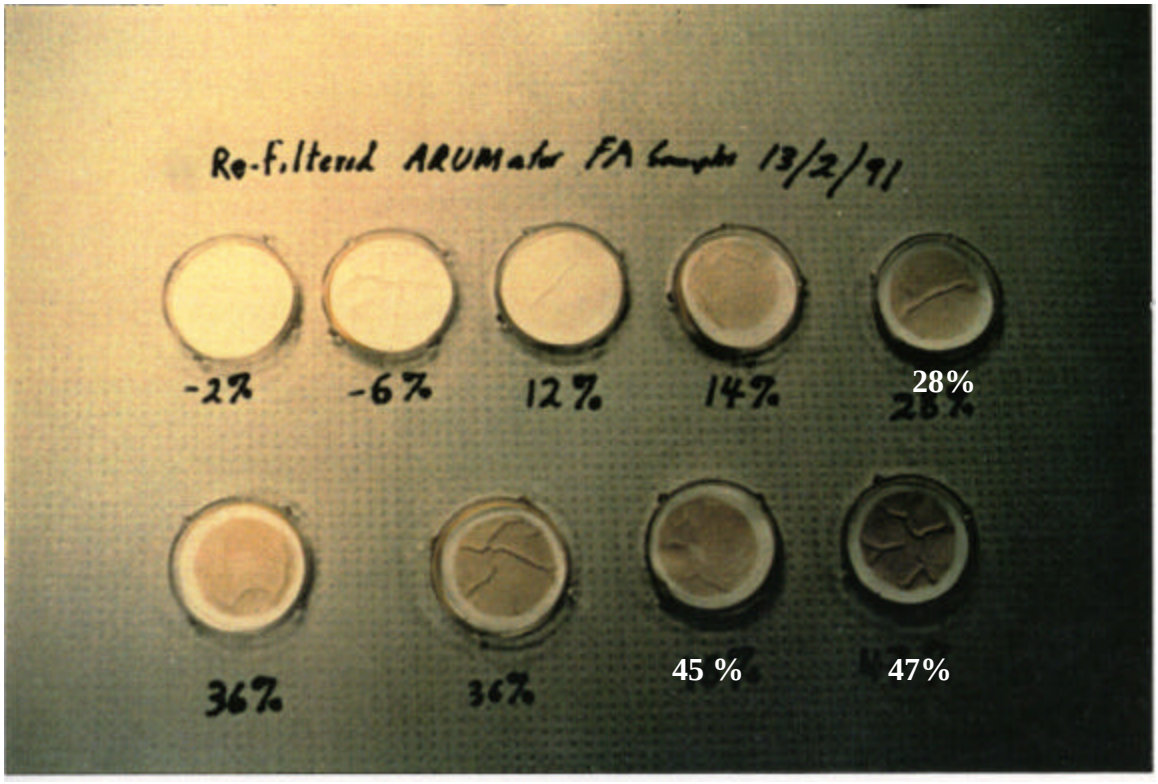


Plate 1: Precipitation of Organics after storage of Filtered and Acidified Samples.

It is suspected that humic acids from the organic amendment caused the ion imbalance in samples from the test cells and ARUMators. These substances affect the inorganic chemical equilibria of the solution by complexing and binding metals.

3.0 THE PERFORMANCE OF THE TEST CELLS SYSTEM

The evaluation of the chemical dynamics of the AMD seepage water discussed in Section 2 requires that the chemistry of the Test Cell System be analyzed in the same manner. The pH changes as seepage water moves through the cells. Changes in pH are evaluated in Section 3.1. Oxidation and subsequent hydrolysis of ferrous ion results in precipitation. The pH changes during this process and sedimentation of the products are discussed in Section 3.2.

Water chemistry in the test cells is analyzed in section 3.3. The factors such as pH and pE controlling the biological and chemical behaviour of the water and the interaction of the ground water with the Test Cell System are presented in section 3.4. In section 3.5 the ground water interactions with the AMD seepage are presented. Finally, in Cells 3 and 4, organic amendment curtains have been installed and the results obtained through August l990 are presented in Section 3.6.

3.1 Flows, Water Level and pH Changes in the System

The comparison of pH values before and after the establishment of flow control in August 1990, demonstrates the necessity of flow control to the ARUM process. A detailed description of the evolution of the Test Cell System is given in Appendix 2.

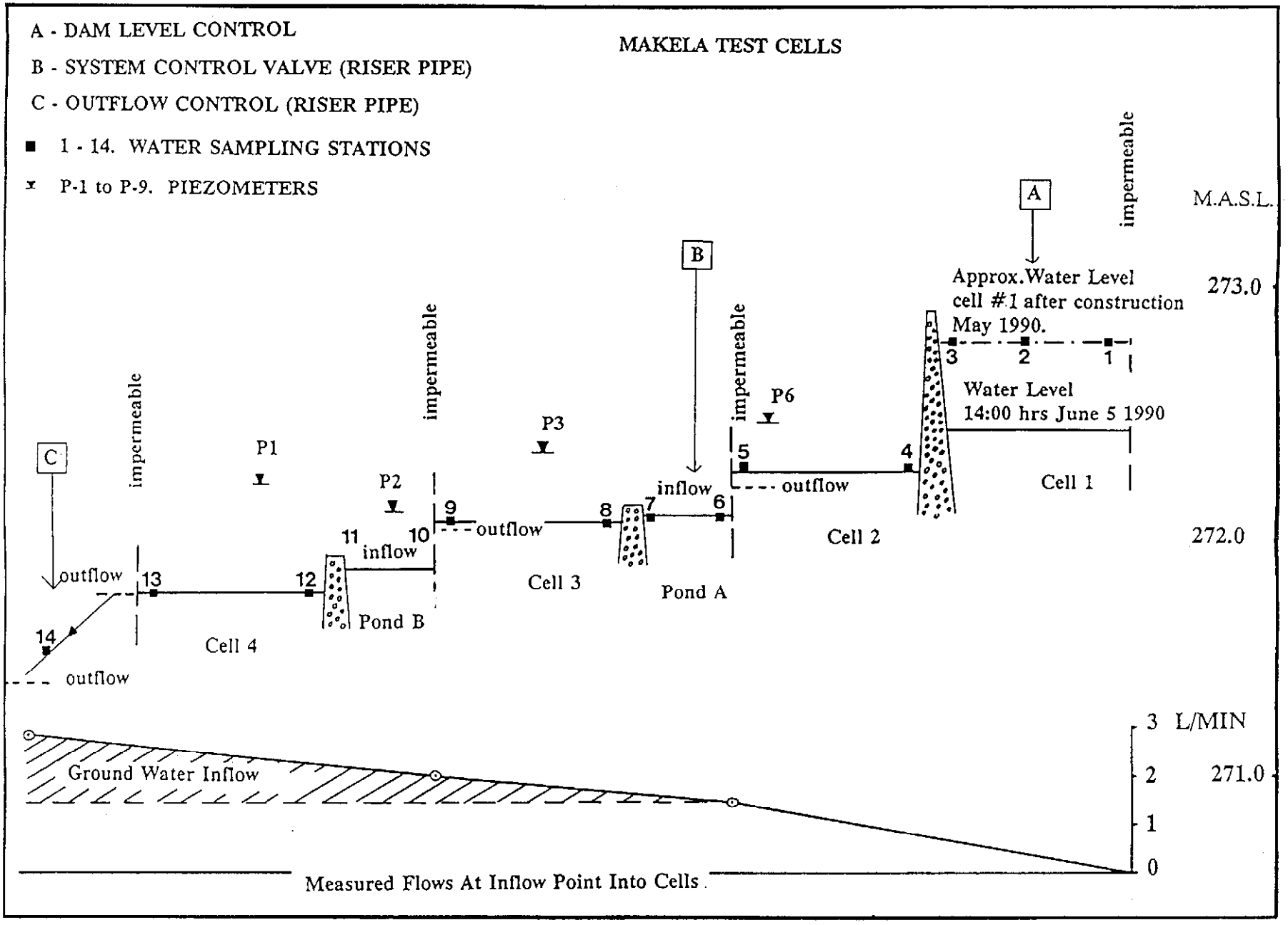
Water in the Makela Test Cell System has been sampled regularly since the construction of the system in August, 1989. The frequency of water sampling and the field measurements of pH, conductivity, temperature, and Eh is summarized in Table 4. The location of sampling stations is plotted in Schematic 1.

Of all the chemical parameters, pH has been measured most frequently. This parameter can therefore serve to illustrate the effect of the physical modifications to the Test Cell System in order to control the flow rates.

Outflow rates and corresponding water levels in the ponds and cells are shown in Figure 6. The effect of outflow rate on the water levels in the cell system is evident.

The results of pH measurements are shown in Figure 7a and 7b for different time periods from August 1989 to May 1990 (Figure 7a). The pH behaviour in the system with flow control (June 1990 - August 8,1990) is contrasted in Figure 7b.

Figure 7a clearly indicates that during the period from August 21 to November 17, 1989, little or no change occurred in the relatively high pH of the water while flowing through the cell system. The relatively high pH values are indicative of incomplete oxidation and hydrolysis of ferrous iron oxides/hydroxides.



Schematic 1: Overview of Makela Test Cell System

Water sampling frequency															
Location	Sp	1	2	3	4	5	6	7	8	9	10	11	12	13	14
21/08/89			x		x		x		x		x		x		x
28/09/89	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
6/12/89		x	x										x		
6/02/90		x			x				x				x		
28/03/90		x			x				x				x		
8/07/80	x		x	x	x		x								x
18/07/90		x	x	x	x	x	x	x	x	x	x	x	x	x	x
8/08/90	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
24/08/90	x						x				x				x
Frequency of pH,Cond., Temp. & Eh measurements (Eh started:8/7/90: (o)= measurement w/ Eh)															
Location	Sp	1	2	3	4	5	6	7	8	9	10	11	12	13	14
21/08/89		x	x	x	x	x	x	x	x	x	x	x	x	x	x
28/09/89		x	x	x	x	x	x	x	x	x	x	x	x	x	x
7/11/89		x	x	x	x	x	x	x	x	x	x	x	x	x	x
15/11/89		x				x	x	x	x	x	x	x	x	x	x
6/12/89		x											x		
6/02/90		x			x				x				x		
28/03/90		x			x				x				x		
18/06/90			x	x	x	x	x	x	x	x	x	x			
27/06/90	x	x	x		x		x		x		x		x	x	x
8/07/90	o		o	o	o		o		o		o		o		o
18/07/90		x	x	x	x	x	x	x	x	x	x	x	x	x	x
8/08/90	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
24/08/90	o						o				o				o

Table 4: Sampling frequency of Makela test cell system

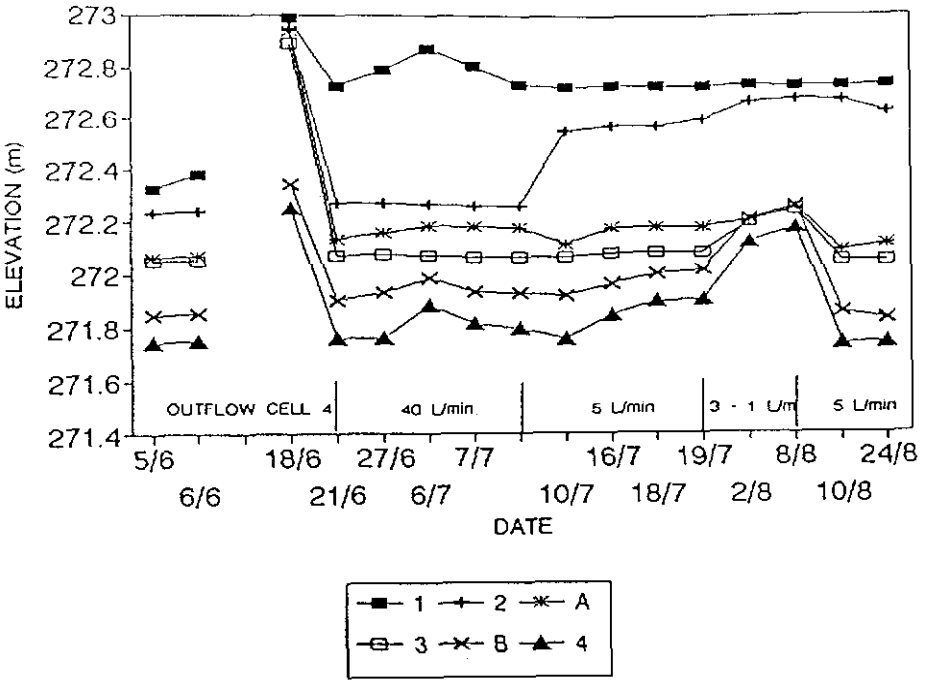


Figure 6: Water Levels in Cells and Ponds, and Corresponding Outflow Rates, 1990.

Measurements of pH taken after the initiation of flow control (June 1990 to present) are plotted in Figure 7b. Measurements of pH before flow control (September 28, 1989) are included for comparison. In addition, the pH of three piezometers: P-1 (Cell 4), P-2 (Pond B), and P-3 (Cell 3) is also plotted. Significant changes in the water pH between inflow (Station SP) and outflow (Station 14) are evident. Furthermore, a considerable difference can be seen between pH values measured before and after flow control.

Three zones differing by pH can be recognized. These are:

- Stn 1 to Stn 3 (Cell 1),
- Stn 3 to Stn 4 (permeable berm between Cells 1 & 2),
- Stn 11 to 13 (Cell 4 with amendment)

The pH values measured in February, 1990 are relatively high. Assuming little or no inflow (frozen inlet structure), the high pH values were most likely the result of ground water discharge into the cell system. The ground water in the immediate vicinity of the system has a pH of 6-7. Fluctuations in pH observed between Stations 11 and 13 appear to be strongly affected by the position of the water level in Cell 4, e.g. exposure of the amendment curtains to the atmosphere. Evidence for this statement is provided by the following observations:

- partial (incomplete) exposure of curtains (July 18); slight increases in pH (Fig.7b).
- totally submerged curtains (August 8); no change, pH similar to Pond B, uniform with depth in Cell 4 as discussed later.
- partially emerged curtains (August 23/24); significant increase in pH, 2-4 units, near base of Cell .

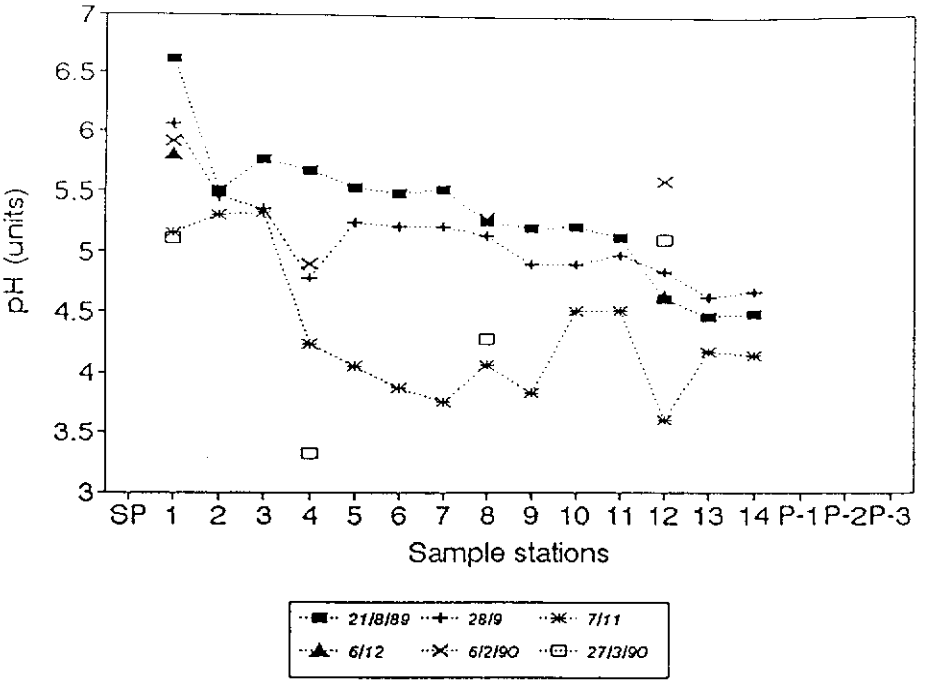


Figure 7a: pH versus Time in Cell System: 21/08/89 - 27/03/90.

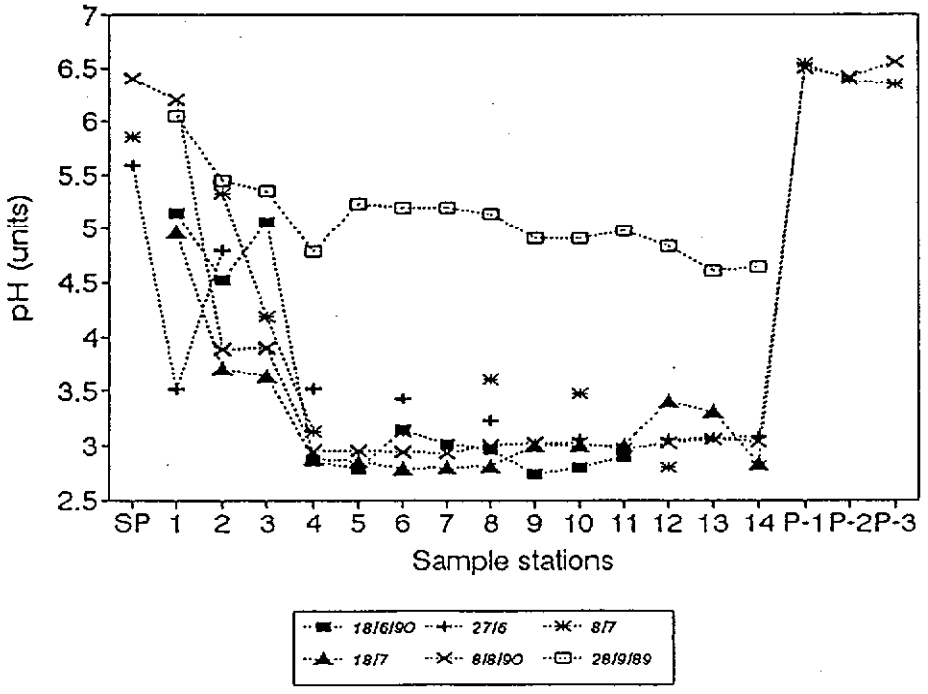


Figure 7b: pH versus Time in Cell System: 18/06/90 - 08/08/90.

Measurements of pH in the system in September 1989 and June-August 1990 clearly demonstrate the effects of flow control (Fig. 7b). Field observations on water in the cells clearly corroborated the differences.

During 1989, prior to December, all cells contained Fe oxides/hydroxides in suspension. During the summer of 1990 only Cell 1 had appreciable amounts of Fe oxides/hydroxides in suspension and all other cells and ponds were clear. Since the summer of 1990, the oxidation and subsequent hydrolysis of ferrous iron compounds in the seepage water (which is accompanied by a significant drop in pH) has occurred between the seep and the inflow to Cell 1, and within Cell 1. The rate of change and its areal distribution is determined by the flow rate through Cell 1.

Between Station 1 and 3, the pH drops 2 - 2.5 units and the rate of change within Cell 1 appears to be a function of the flow rate through Cell 1 (Figure 8). Lower flow rates, i.e. longer residence times, are associated with greater change (drop) in pH. A further significant drop, 1 - 2.5 units, takes place across the permeable berm between Cells 1 and 2 (Stn 3 - 4). The change observed across the permeable berm (Stn 3 - 4) is somewhat surprising.

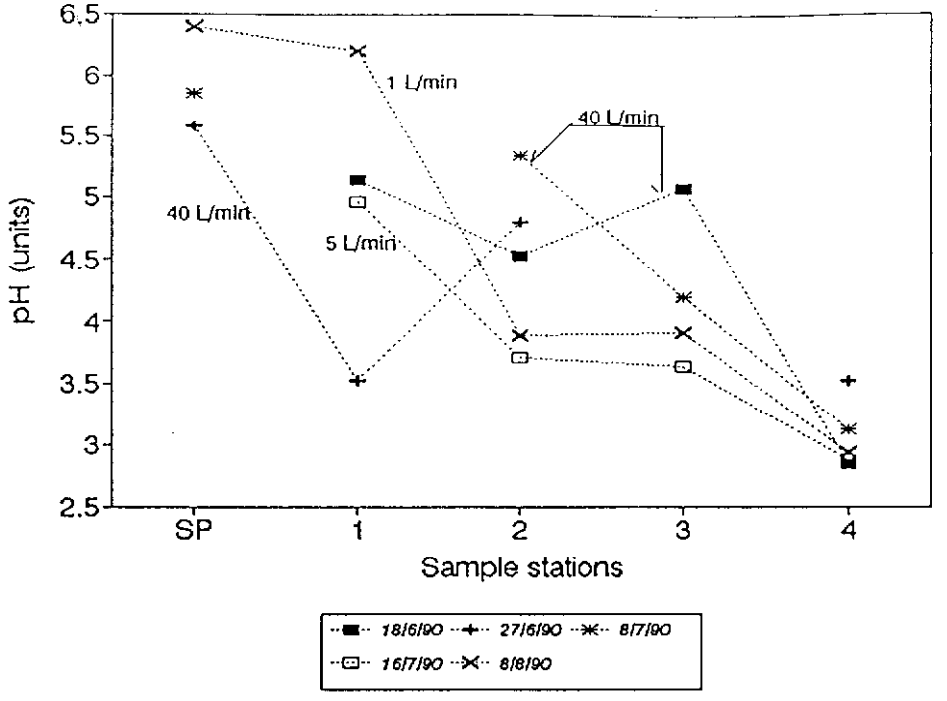


Figure 8: pH of Sample Stations, Seep, STN 4 and Flow Rates: 18/07/90 - 24/08/90.

It was suspected that the berm material contributed to the change and static leaching tests, using Cell 2 and distilled water on the crushed rock comprising the berms, were carried out. In Figure 9, sequential pH measurements of the berm and Cell 2 water leaching test are plotted. The results suggested that when AMD seepage and berm material are combined, a somewhat active chemical environment is produced.

A significant increase in pH, from 3 to 6 occurred after approximately 300 hrs (12.5 days), which persisted and only slightly decreased after 1400 hours. No carbonate minerals/rocks were present in the crushed gravel. The neutralization capacity is suspected to occur through dissolution of feldspars and calc-alumina-silicates in the Cell 2 water. The results from the static leach test, however, were contrary to field pH observations, where a chemical change, rather than a pH increase, was noted. The leach tests, however, suggest that when AMD is initially in contact with the gravel, a chemically active environment is encountered. The elemental composition of Cell 2 water used in the experiment is given along with the composition of the elements after the static leach tests in Table 5. Although increases in some of the elements are possibly within analytical error range, they, nevertheless, support the idea of a chemically active environment in the berm.

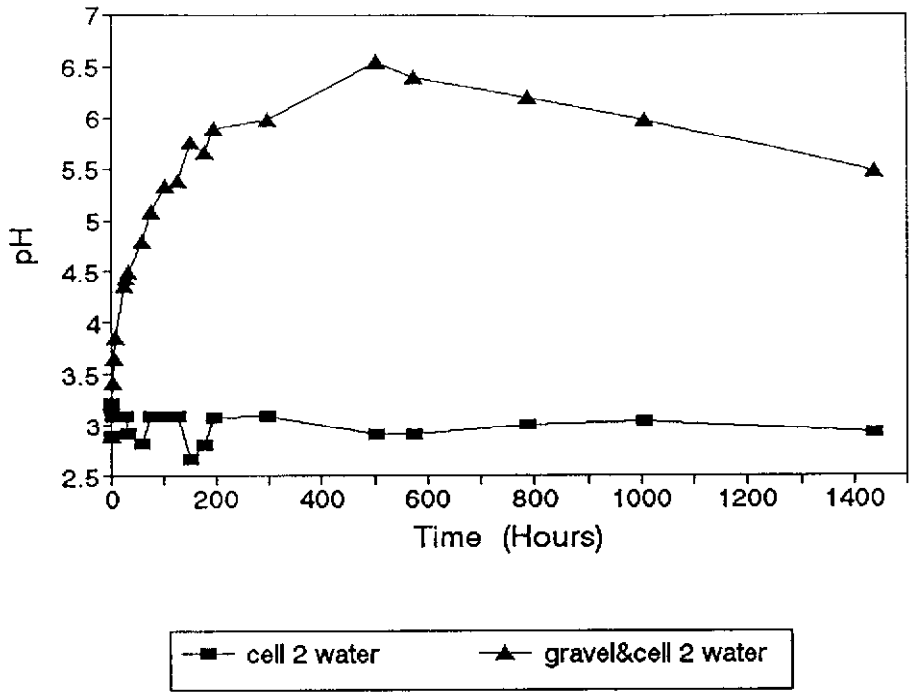


Figure 9: Leaching Experiments: Makela Gravel Berm with Cell 2 Water.

SAMPLE DATE		21-Jan-91		21-Jan-91	
SAMPLE VOLUME		100		100	
ASSAYERS CODE		2457		2461	
SAMPLING LOCATION		MAKELA Water		MAKELA Gravel New	
Processing code		FA		FA	
** L A B **					
Temp. (C)		20.5		20.5	
pH		2.97		4.82	
Cond. (umhos/cm)		2850		2800	
Eh (mV)		497		306	
ELEMENTS Al		0.3	<	0.01	-
B		0.4		0.4	
Ba	<	0.01		0.03	+
Ca		406		477	+
Cd		0.02	<	0.01	-
Co		0.8		0.1	-
Fe		2.2		0.2	-
K		78		38	-
Mg		160		198	+
Mn		25		21	-
Na		149		192	+
Ni		23		9.1	-
P		0.05		0.07	+
Pb		0.05	<	0.01	-
S		719		771	+
Si		7.1		9.9	+
Sr		2.7		3.8	+
Zn		2.4		0.1	-

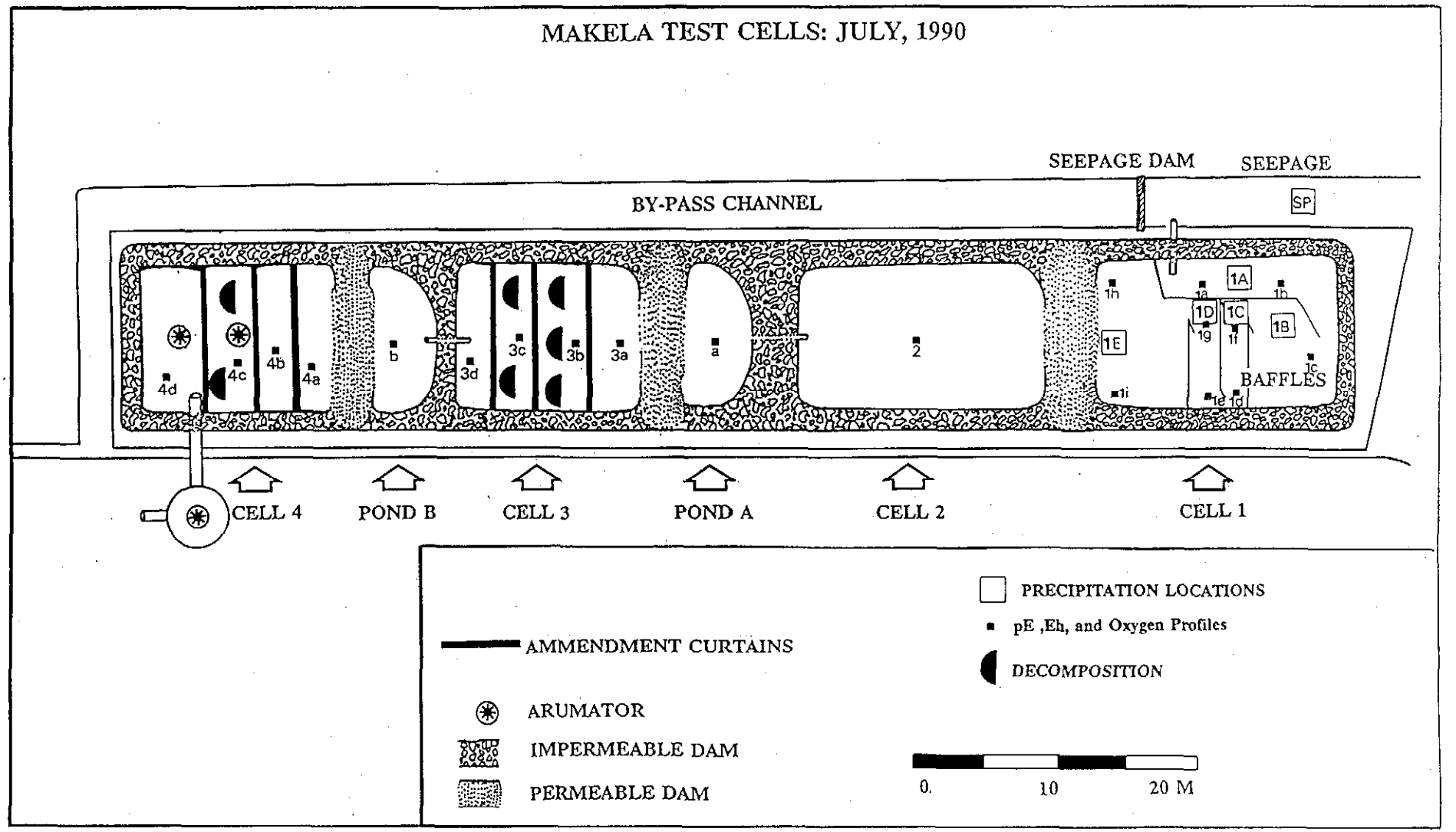
Table 5: Elemental Concentrations in Cell 2 Solutions Before and After Leaching Berm Gravel.

3.2 Iron Hydroxide Precipitation in Cell #1 and Sedimentation

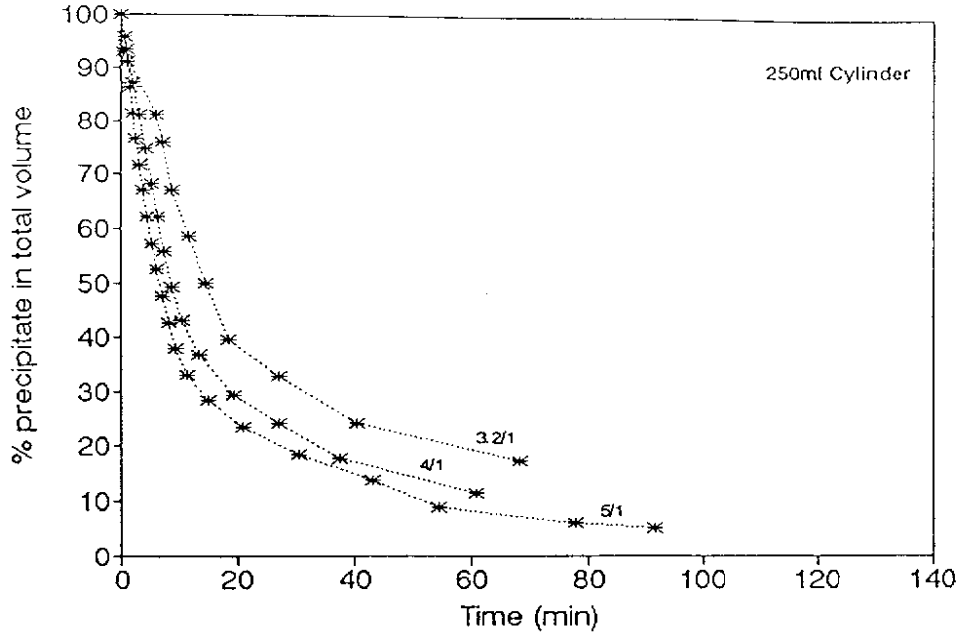
Field observations have shown the presence of ferric oxides/hydroxides in all Cells, and transport through and out of the system. Approximately 10-15% of the suspended Fe oxides/hydroxides entering the system, leave the system (Kalin 1990). Inflow rates into the system before flow control were on the order of 30 - 60 L/min (0.5-1 L/sec). Residence time was measured as 95 minutes for the total system. Sedimentation rates determined during high flow and over the winter l990 ranged from close to 50 g/m^2/day to less than 25 g/m^2/day between Cell 1 and Cell 4 (from Kalin l990).

Buckets were placed in the seepage ditch, Cell 1, Cell 2, and Pond A to collect precipitate at these locations. Schematic 2 indicates the locations of the buckets. The buckets were placed on July 10, 1990 and recovered on August 9, 1990. After recovery of the buckets, the precipitate was allowed to settle for at least 24 hours before the supernatant water was decanted and the precipitate collected.

Settling experiments were carried out to determine if differences in the nature of precipitate existed. Details of the methods are given in the Appendix 2.The settling rates of the precipitate in Cell 2 and Pond A are presented in Figures 10 and 11.



Schematic 2: Makela Test Cells: July 1990



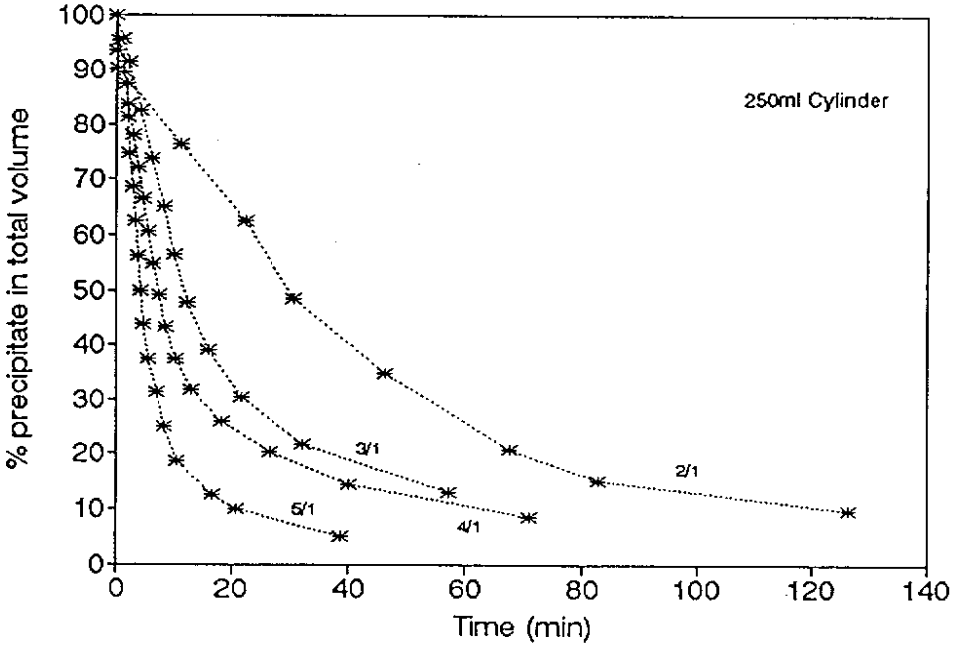
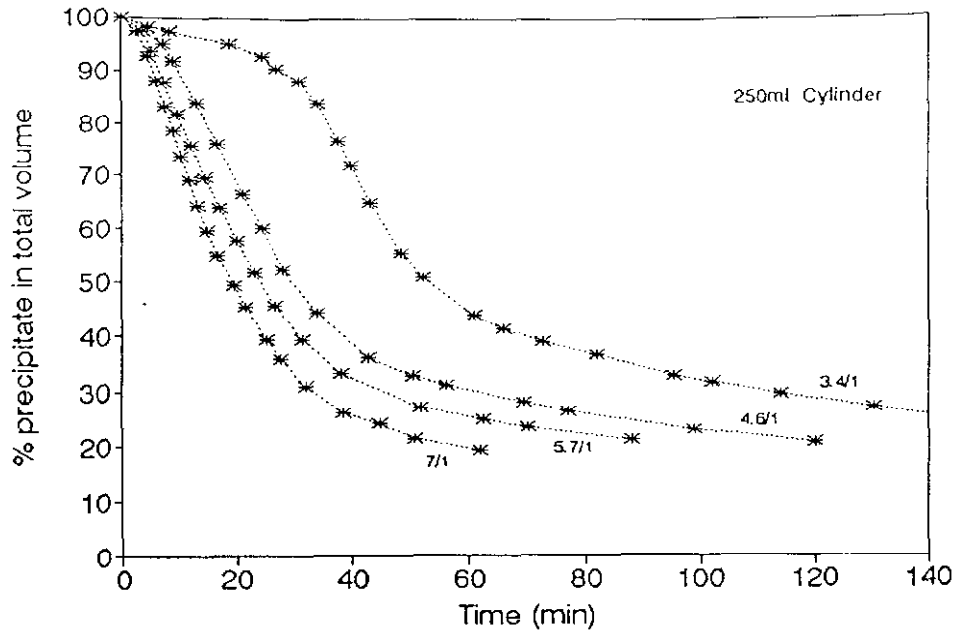


Figure 10: Precipitate Settling, Pond A and Cell 2: Different Liquid/Solid Ratios.



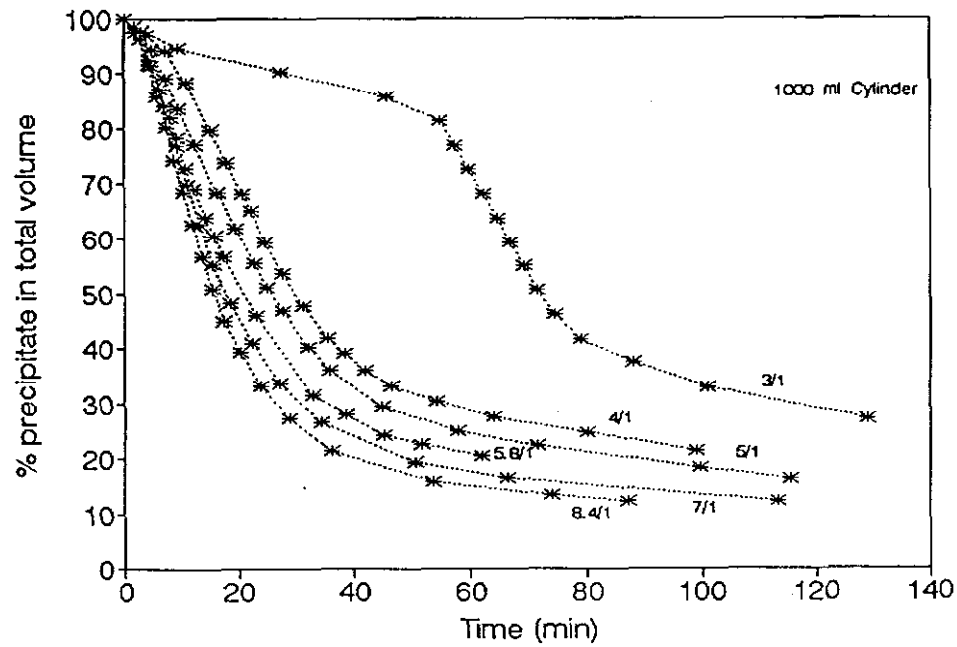
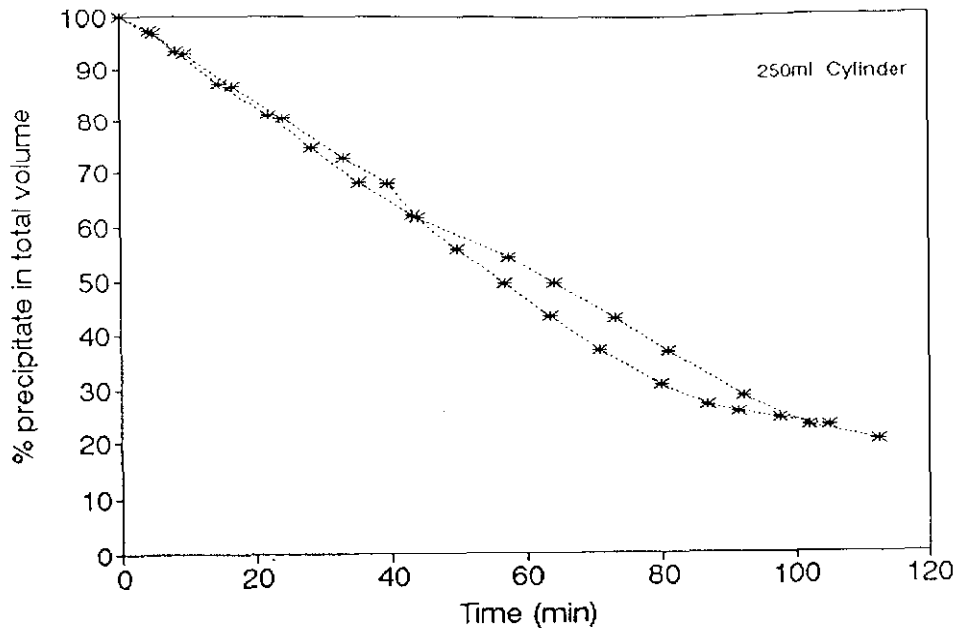


Figure 11: Precipitate Settling, Sample Cell 1-A: Different Liquid/Solid Ratios. 250 mL and 1000 mL cylinders.

Figure 10 describes the different liquid to solid ratios on the settling behaviour, whereas Figure 11 demonstrates the effect of graduated cylinder size used in the experiments. The latter effect was considerably less than the former. The high reproducibility of sedimentation rates within the experimental conditions is shown in Figure 12.

The settling behaviour of sludges collected from various locations throughout the cell system indicates that there are differences in the precipitate formed (Figure 13a and Figure 13b). The sampling locations are given in Schematic 2. As can be seen, considerable variation is present between samples, but no uniform change can be detected. It is not known if the variability is due to chemical differences between the precipitates, flow characteristics within the Cell, or both. The progressively different settling behaviour of the sludges from the seepage ditch through Cells 1 & 2 into Pond A can be seen in Figure 13b.

To test if this difference is persistent under different temperature regimes, precipitate which had accumulated at the same locations in the test Cell 1 between August 10 and November 22, l990 was settled under the same conditions as before (250 mL cylinder; liquid /solid ratio of 5/1; Figure 14). Each sampling location had a different settling rate. The seepage precipitate prior to Cell #1 was most homogenous during the summer and the fall. The precipitate formed in the seepage ditch was closer in settling behaviour to locations 1-E, 1-B (Figure 13a).



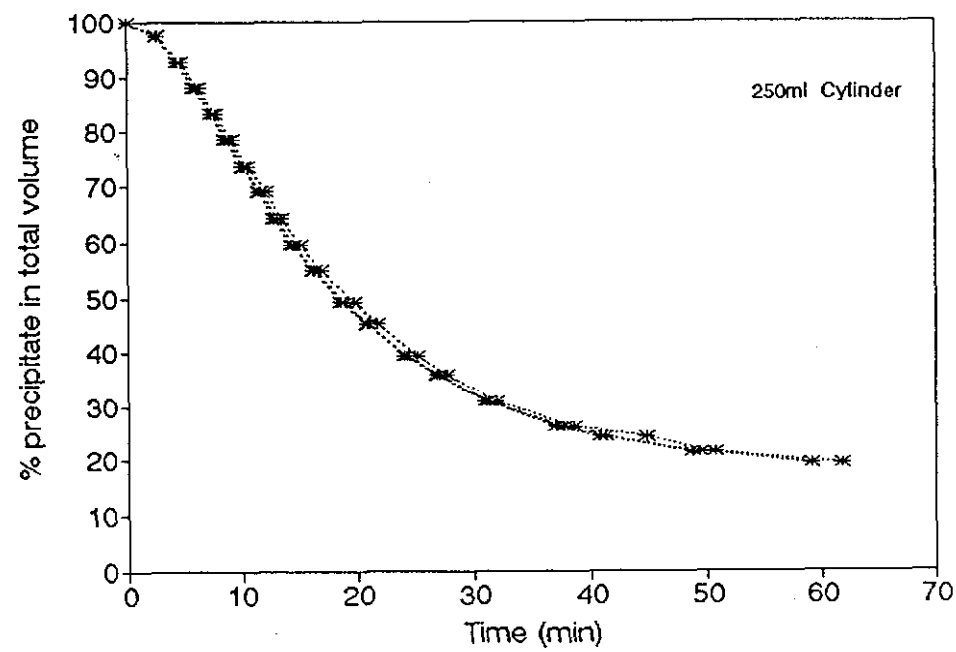


Figure 12: Precipitate Settling: Repeats for Different Liquid/Solid Ratios.

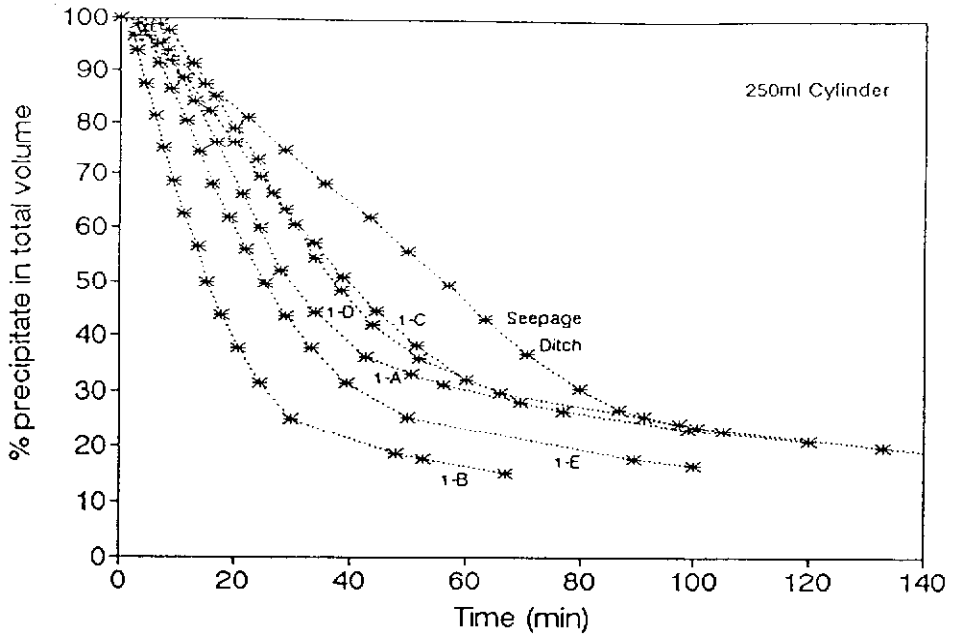


Figure 13a:Precipitate Settling: Cell 1, Liquid/Solid Ratio = 5/1.

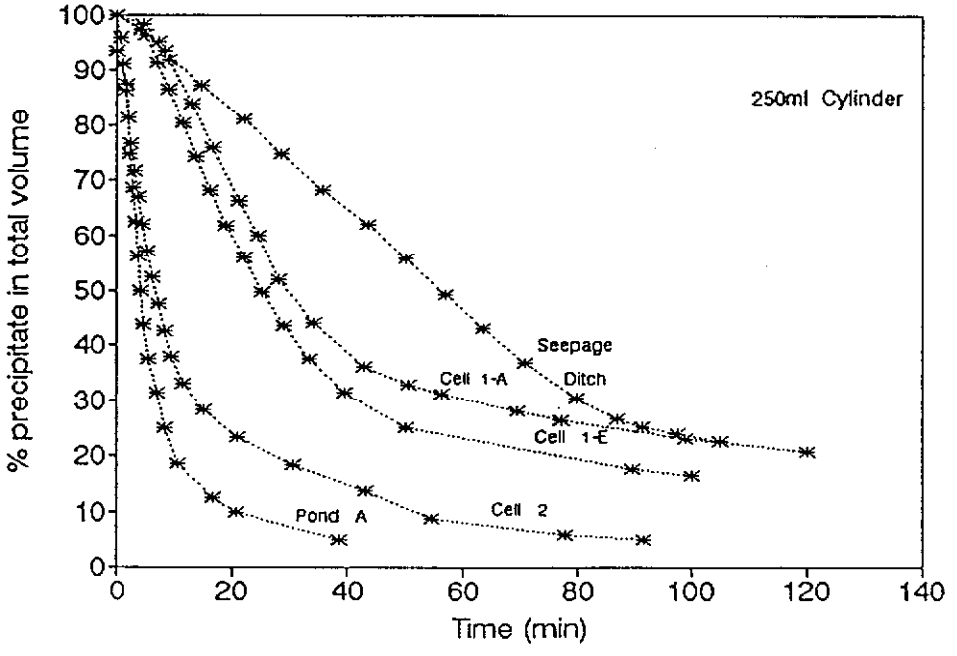


Figure 13b:Precipitate Settling: Ditch, Cell 1, Cell 2 and Pond A, Liquid/Solid Ratio = 5/1.

It should be noted that the settling time of 140 min is an arbitrary cut-off point and therefore the differences in settling rates are a reflection of differences in weight of the precipitate. The differences in precipitate formation are in all likelihood the result of chemical changes, the rate of which is determined by the temperature. This contention is further supported by significant differences in the dry weight per mL of sample slurry (Figure 15). The dry weights per total volume settled were consistent with the location. Lower quantities were formed in November samplings than in August samplings, which had accumulated precipitate over the summer. Precipitate formation, then, seems to be controlled by temperature and by chemical changes in the AMD.

3.2.1 Chemical Composition of the Precipitate

The precipitate from the seepage ditch and Pond A were submitted for X-ray diffraction analysis. The following crystalline constituents were detected:

Seepage Ditch: Quartz, Feldspar, Goethite, Mica and (?)Jarosite.

Pond A: Quartz, Feldspar, Jarosite, and Burkeite.

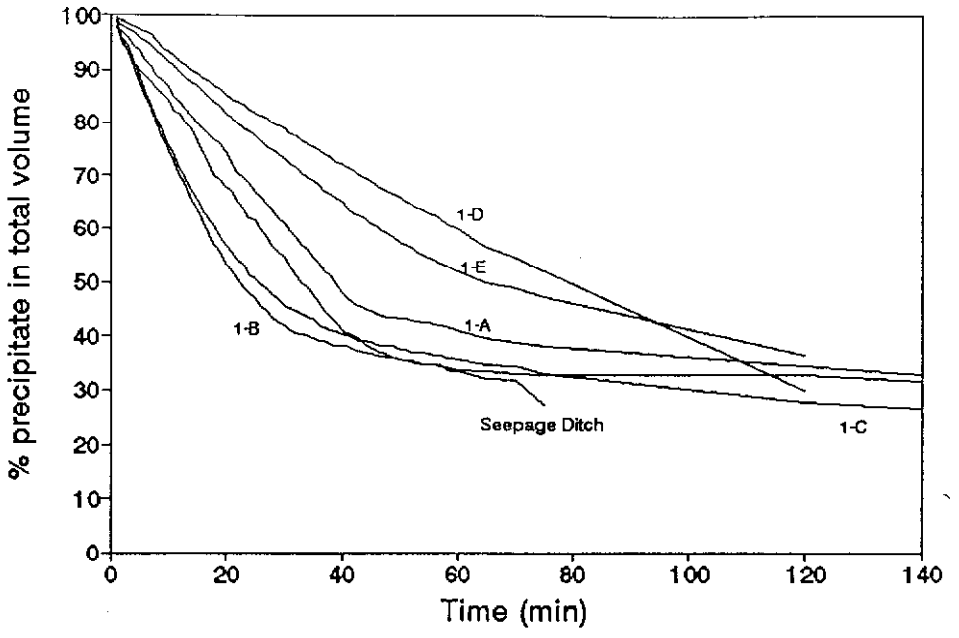


Figure 14: Precipitate Settling: Cell 1, Liquid/Solid ratio = 5/1.

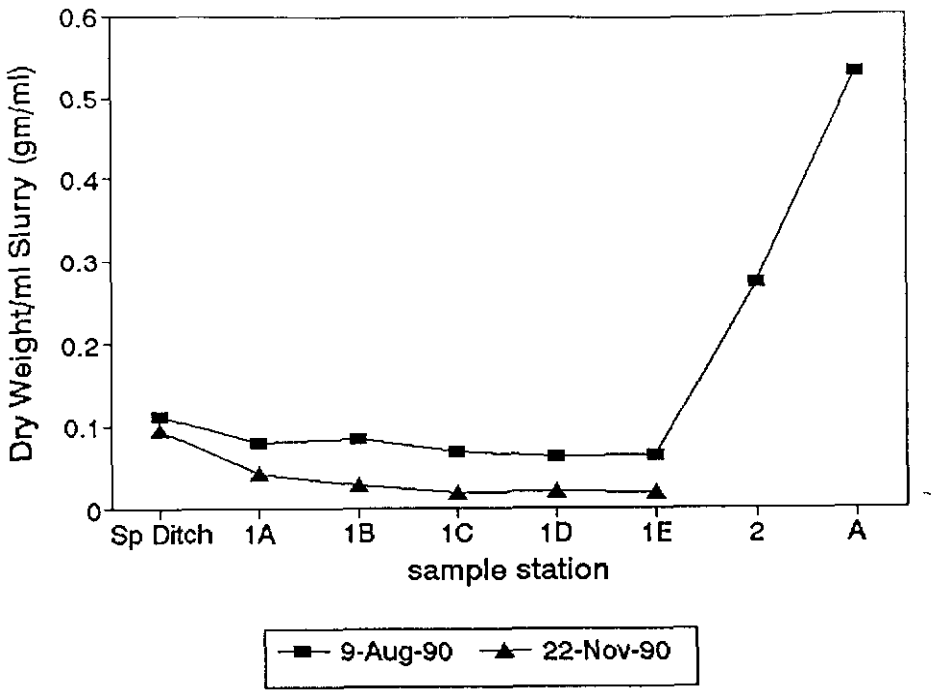


Figure 15: Precipitate Cells: Dry Weight/mL of Slurry. Samples collected August 9, November 22, 1990.

The results obtained for the seepage ditch are similar to those obtained for a precipitate sample from Cell 4 in 1989. The main difference is the absence of gypsum in the more recent sample. This is somewhat surprising, since it is known that the water in the Cells is saturated with respect to gypsum. Drying of the precipitate sludge would have resulted in the precipitation of crystalline gypsum. It is not known why gypsum was not detected. The change from goethite to jarosite between the ditch and Pond A clearly shows not only a change in the type of iron mineral, but also indicates a considerable improvement in the degree of crystallinity of the iron mineral. This in turn could explain the difference in settling behaviour.

3.2.2 Geochemical Simulation

Determination of mineral precipitation through analytical methods is difficult, particularly given the highly amorphous nature of the precipitate. The geochemical simulation program PHREEQE was used to determine if seepage water in the Test Cell System and the ARUMator samples showed saturation with respect to any of the metal sulfides listed in Table 6. Saturation would indicate whether these waters could be capable of precipitating such minerals. Because of availability of Eh data, only samples collected in July and August were used for the PHREEQE simulation. [Cl] values had to be estimated on the basis of earlier analyses.

Output files from the simulations (ASCII print files) were imported into LOTUS 123 for editing, and converted to numerical worksheet files to enable further calculations. Tables F-1 to F-4 present all the saturation degrees calculated as LOG(IAP/KT) values for seepage and feed water, and for the ARUMators #1, #2, and #3, respectively. The tables are presented in Appendix 1.

Table 7 presents a summary of the signs of the saturation degrees for the metal sulfides, sulfates, carbonates, and hydroxides based on the results given in the Appendix 1 (Tables F-1 to F-4). Positive signs indicate saturation, negative signs no saturation.

All the samples show some supersaturation with respect to: alunite, barite, cristobalite, gypsum, hematite, quartz, and cuprous-ferrite. In addition to these, seep samples were saturated with respect to: ferrihydroxide, goethite, jarosite, maghemite, magnetite, and cupric-ferrite.

The higher pH values in ARUMators #1 and #2 gave rise to some supersaturation with respect to $Al(OH)_3$, $Al_4(OH)_{10}$, boehmite, calcite, dolomite, gibbsite, magnesite, siderite, and rhodochrosite. Low pE values were accompanied in some or all of these samples by supersaturation with respect to: pyrite, Cu-metal, cuprite, chalcosite (djurleite/anilite/blaublei) and covellite, chalcopyrite, sphalerite, otavite, greenockite, and galena.

MINERAL	COMPOSITION	COMMENTS
ALABANDITE	MnS	
BORNITE	Cu_5FeS_4	
CHALCOCITE	Cu_2S	
CHALCOPYRITE	$CuFeS_2$	
COVELLITE	CuS	
GALENA	PbS	
GREENOCKITE	CdS	
MARCASITE	FeS_2	
NICCOLITE	NiS	
PYRIYTE	FeS_2	up to 60% Ni, rare
PYRRHOTITE	$Fe_{1-n}S$	$0<n<0.2$; minor Ni, Co, Mn
SPHALERITE	ZnS	up to 28% Fe; minor Mn or Cd
WURZITE	ZnS	

Table 6: Potential metal-sulphide precipitates

Summary of LOG(IAP/KT) signs from PHREEQE output for metal sulfides,sulfates,carbonates,and (hydr)oxides

SAMPLE	JUL		AUG		ARUM-1				ARUM-2				ARUM-3					
SOURCES	S	F	S	BP	H	T	M	B	H	T	M	B	T	M	B	T	M	B
Al(OH)3	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-
AlOHSO4	-	-	-	+	+	-	+	-	+	-	-	-	-	-	+	-	+	+
Alunite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Al4(OH)10	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	+	+	+
Anhydrite	-	+	-	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+
Aragonite	-	-	-	-	-	+	-	-	-	+	+	+	-	-	-	-	-	-
Barite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Boehmite	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	+	+
Calcite	-	+	+	+	-	+	+	+	-	+	+	+	-	-	-	-	-	-
Chalcedone	+	+	-	+	-	+	+	+	-	-	+	+	+	+	+	+	+	+
Cristobalite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Diaspore	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
Dolomite	-	-	-	-	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Ferrihydroxide	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe3(OH)8	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe(OH)2.7	+	+	+	+	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Gibbsite	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Goethite	+	+	+	+	-	-	-	+	-	-	+	-	-	-	-	+	-	+
Gypsum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Hematite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Jarosite	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maghemite	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnesite	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-
Magnesioferrite	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnetite	+	+	+	+	+	+	-	+	-	+	+	+	-	-	-	+	+	+
Pyrite	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Quartz	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Siderite	-	-	-	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-
Rhodochrosite	-	-	-	-	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Cu metal	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Cuprite	-	-	-	-	+	+	+	+	-	+	+	+	-	-	-	-	-	-
Chalcosite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Djurleite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	-
Anilite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-
Blaublei	-	-	-	-	+	+	+	+	+	+	+	-	+	+	+	-	-	-
Covellite	-	-	-	-	+	+	+	+	+	+	+	-	+	-	+	-	-	-
Cupricferrite	+	+	+	+	-	-	-	-	-	-	+	-	-	-	-	-	-	+
Cuprousferrite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chalcopyrite	-	-	-	-	+	+	+	+	+	-	+	-	+	-	+	-	-	-
Sphalerite	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Otavite	-	-	-	-	-	+	+	+	-	+	+	+	-	-	-	-	-	-
Greenockite	-	-	-	-	+	+	-	-	+	-	-	-	-	-	+	-	-	-
Galena	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-

S- Seepage; F- Feed water; BP- End of by-pass channel.
H- Homogenized; T- Top; M- Middle; B- Bottom.

Table 7: Geochemical simulation results

3.2.3 Factors Controlling Precipitation

pH and Redox Potential (Eh and pE) along with temperature are likely the most important factors which affect the precipitation behaviour, either brought about through exposure to the air or by the microbial activity. Therefore, a detailed investigation of the redox conditions is required.

Eh values, in millivolts, corrected for temperature and reference-electrode potential, were divided by 59.2, to obtain pE values for use in geochemical calculations and in pH and pE graphs. Eh is the redox potential and is a measure of the oxidation/reduction state of a solution, i.e. the ratio of the activity products of oxidized/reduced ion species(for example: ferric/ferrous). Eh measurements can therefore be readily used to determine if anaerobic conditions exist or are developing or, for example, to measure the degree of oxidation of iron compounds. A calomel/platinum electrode combination was used to measure Eh. In Appendix 2, a listing of the units associated with Eh is presented.

In Figure 16 A, pH vs. pE relationships for July and August samples (a) from the seep, (b) from the piezometers, (c) from the Cells and ponds, and (d to f) from the three ARUMators are summarized. The piezometer samples are identified by piezometer numbers 1 to 9; samples from the three ARUMators are distinguished by symbols 1, 2 and 3 and the sample types by letters (H=homogenized, T=top port, M=middle port, and B=bottom port). Table 8 gives the ranges of pH, Eh, and pE for the 6 groups of

samples. Most of the piezometer samples had somewhat higher pH and pE values than the seepage samples. The exceptions were one sample from P-5 and both samples from P-7.

The plotted points for the Cell samples show a generally progressive change to lower pH and higher pE values, reflecting progressive oxidation and hydrolysis of the originally available ferrous ions. The locations of the 2 points representing the samples from P-7 suggest that those samples may be a mixture of ground water and water infiltrating from Cell 1 or Cell 2.

RANGES of pH, Eh, and pE for VARIOUS SOURCES							
SAMPLE	SOUR	Seep	Piez.	Cells	ARUM-1	ARUM-2	ARUM-3
pH, units	MAX	6.40	6.95	6.20	6.74	6.65	6.28
	MIN	5.85	5.11	2.79	6.01	5.61	4.44
Eh, mV	MAX	208	413	690	-34	-31	140
	MIN	159	161	227	-96	-109	27
pE, units	MAX	3.510	6.982	11.658	-0.580	-0.532	2.372
	MIN	2.690	2.712	3.835	-1.622	-1.842	0.452

Table 8: pH and REDOX Data

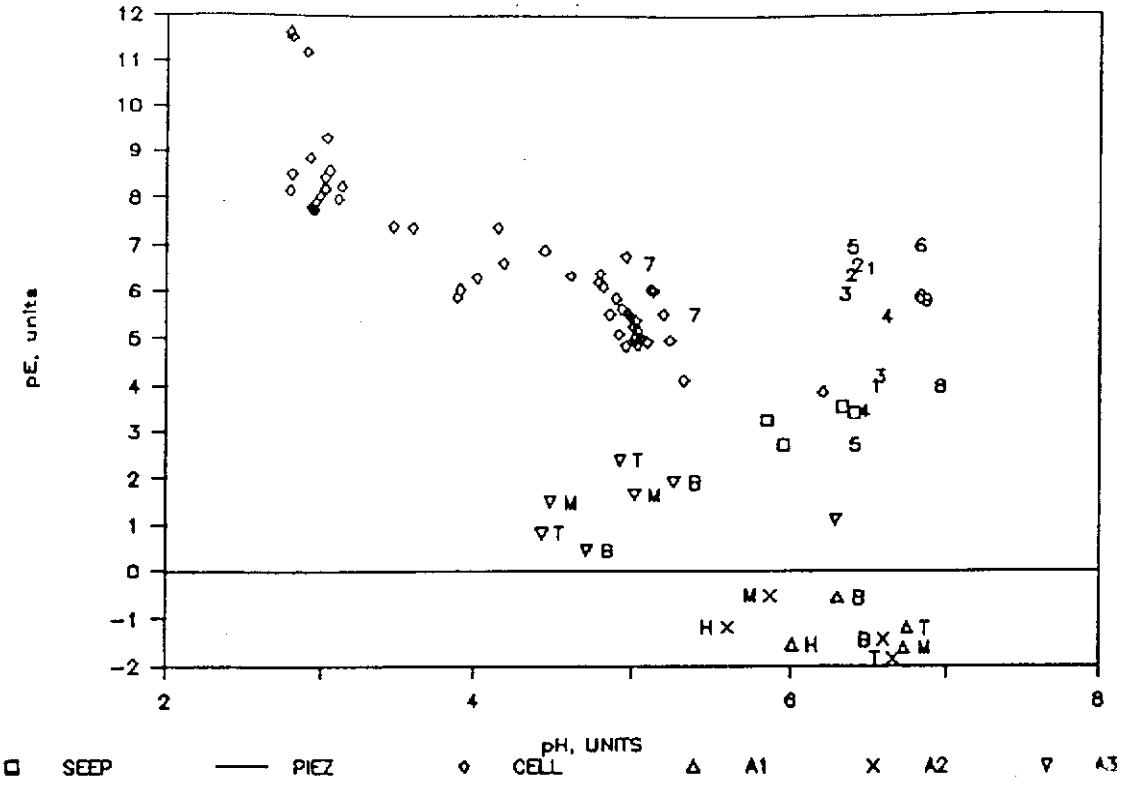


Figure 16a: pE vs pH in Makela test cell system and Arumators

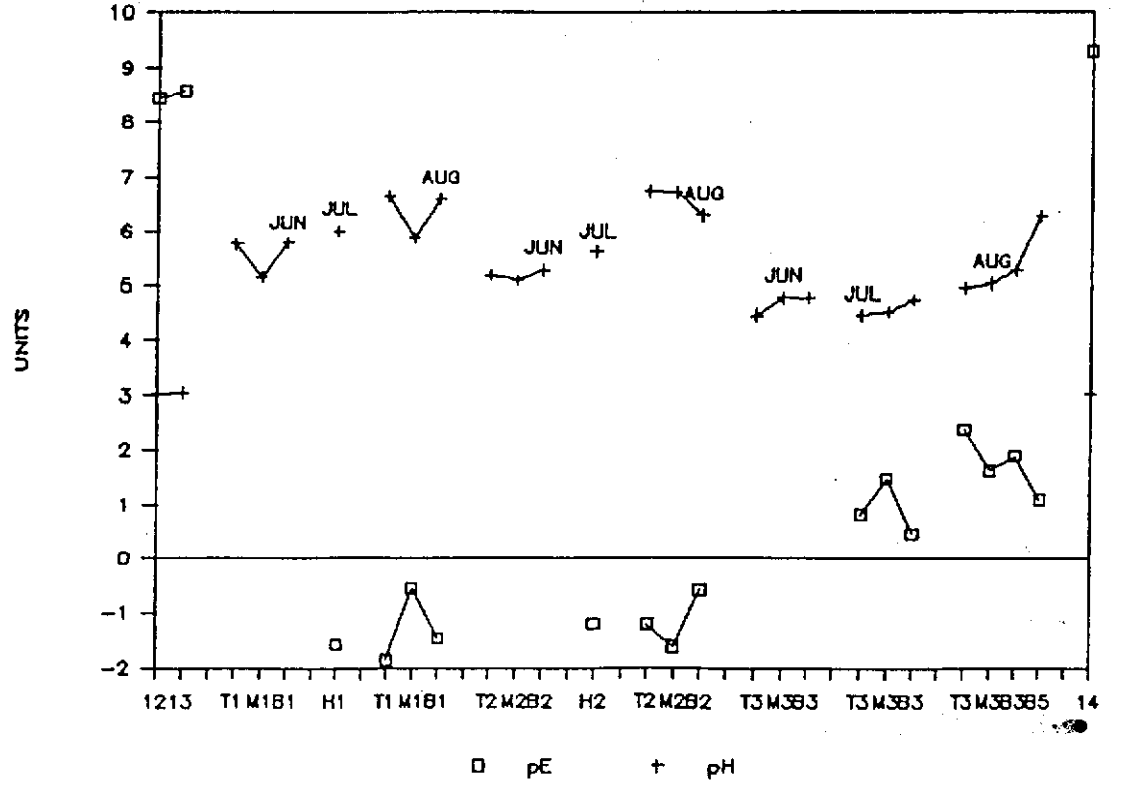


Figure 16b: pH and pE in Makela Arumators for June to August

Figure 16B presents the available pH and pE data for the samples collected from the three ARUMators in June, July and August. (Eh values were not measured in June). ARUMators #1 and #2 had pH values similar to or slightly higher than the pH of seepage water, with Eh decreased to between -30 and -110 millivolts. ARUMator #3 had pH values similar to samples from the upstream portion of the treatment system, with Eh decreased to between +25 and +140 millivolts. Barnes et al. (l991) indicate that a redox of -100 mV is sufficient for sulphate reduction. Methanogens, on the other hand, require a minimum redox of -300 mV. The measurements obtained in the ARUMators 1 and 2 are therefore just about at the stage where sulphate reduction can be expected, while methanogenesis will require further depression of redox. This concurs with the results obtained to date in the headspace of the ARUMators, which have been free of methane.

The low-pE and 'high'-pH conditions found on both dates in the ARUMators #1 and #2 were potentially favourable for precipitation of at least some of the metal-sulfide minerals listed in Table 6. The lower pH and higher pE found in ARUMator #3 were not favourable for the precipitation of metal-sulfides.

Eh/pH measurements in the precipitation Cell #1 have been carried out with respect to depth. Eh/pH profiles were measured in Cell 1 on June 9 and August 9, 1990 and in all other cells and ponds on August 9, 1990.

The location of the Eh/pH profiles in the cells and ponds is shown in Schematic 2. The pH measurements on June 9, 1990 in Cell 1 are plotted in Figure 17 and pE is presented for the same location and the same date in Figure 18. Note that only those profiles with 3 or more measurements are shown. The sampling stations are arranged in the direction of flow. A very uniform pattern of both the distribution of the Eh and pH with depth was apparent. In all cases the pH increased slightly with depth, while the pE invariably decreased with depth. This particular distribution of the pH and the pE indicated that oxidation of ferrous iron is more rapid near the water surface, decreasing with depth. This is supported by the dissolved oxygen distribution in Cell # 1 water (Figure 19). The oxygen content with depth (> 20 cm) rapidly decreases with an increase in distance from the inflow. The oxygen content in the upper 15 cm of the cell water, however, shows not only an increase with respect to the inflow but also considerable variability throughout the cell. It appears therefore that significant oxygen exchange between air and water takes place, but little diffusion with depth.

This apparent lack of penetration of the atmospheric oxygen could be due to the absence of wave action and turbulence or is perhaps indicative of immediate consumption by the oxidation of the ferrous iron in this layer. It should be noted that baffles were installed in Cell 1 to prevent short circuiting in that cell.

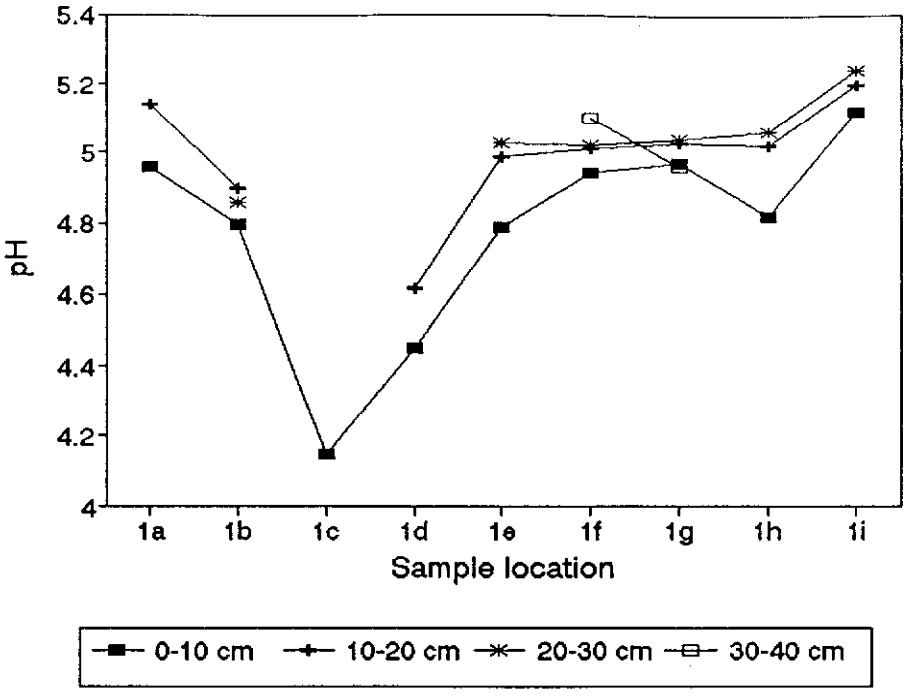


Figure 17: pH of the Upper 40 cm of the Water Column of Cell 1: June 9, 1990.

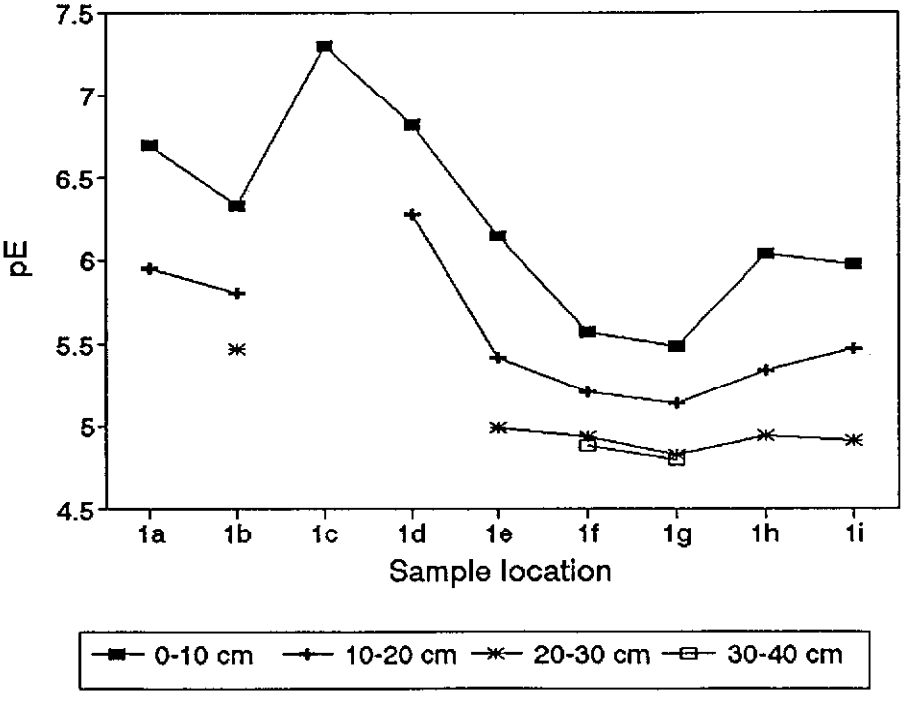


Figure 18: pE of the Upper 40 cm of the Water Column of Cell 1: June 9, 1990.

A reasonably good correlation exists between dissolved oxygen content, pE, and depth for the values obtained in Cell #1 in June 9 and on August 9, 1990. The values for pE and pH at the greatest depth in each locality are measurements within the precipitate layer. The localities 1-a and 1-b show elevated pH values at a depth of approximately 20 cm. This depth corresponds with the position of the inflow pipe below the water surface. This relatively well defined zone with higher pH and the slight drop in the position of this zone downstream from the inflow indicates gravity flow as a result of temperature differences between cooler inflow water and the warmer cell water. By the time the water has reached locality 1-c, sufficient mixing and dispersion has taken place that this effect has disappeared. A general drop in the pH can also be noted over this reach, which is accompanied by an increase in the pE.

Beyond STN 1-c, after the oxidation of ferrous iron, pH remains more or less constant (Figure 20). The pE shows a slight decrease with depth in the majority of the locations and the minimum value is reached immediately above the precipitate layer. Within the precipitate layer, the pE increases again and the pH decreases. Although this suggests further oxidation of ferrous iron, previous measurements (June 9,1990) indicated that this zone is oxygen depleted. (Note: oxidation from Fe^{2+} to Fe^{3+} without precipitation causes an increase in pH).

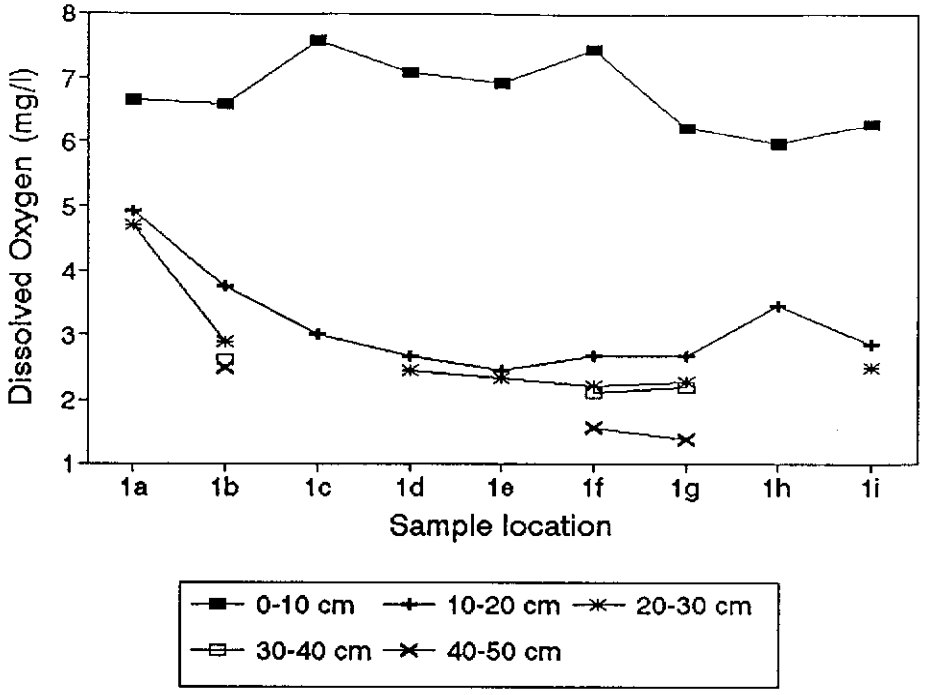


Figure 19: Dissolved Oxygen Concentrations in the Upper 50 cm of the Water Column of Cell 1: June 9, 1990.

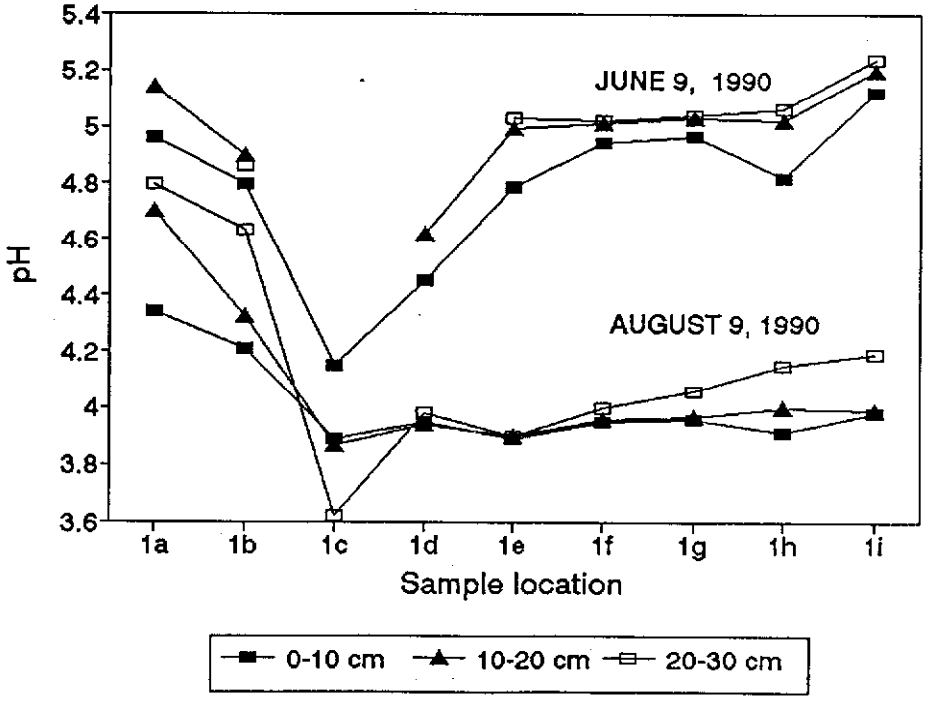


Figure 20: pH in the Upper 30 cm of the Water Column of Cell 1: June 9 and August 9, 1990.

A comparison of the profiles measured on August 9, 1990 with those measured on June 9, 1990 shows that the pH on August 9 is lower than in June (Figure 20). Furthermore, the magnitude of the difference in the pH value between the two dates increases with the length of the flow path in Cell 1. In addition, there is much less differentiation with depth in the pH and pE values. This indicates a greater and more uniform degree of oxidation of ferrous iron species in Cell 1 in August. This is not too surprising if it is considered that the flow rate in August was considerably less: 1-2 L/min versus 40 L/min.

The pE and pH profiles in the rest of the cell system are plotted in Figures 22 and 23; pH in Figure 22 and pE in Figure 23. pE and pH have a very uniform distribution in both Cell 2 and Pond A. In comparison to Cell 1, a considerable drop in both parameters has occurred between Cell 1 and 2. A slight further drop in the pE takes place in Pond A. This latter drop is in all likelihood due to further aeration which takes place at the flow control valve. Cell 3 shows constant pH values throughout, but minor decreases with depth are present in the pE values.

This could be due to relatively stagnant water conditions in the sub-cells in combination with organic loading from the amendment curtains, which would create, with time, anaerobic conditions with the indication of significant biological activity.

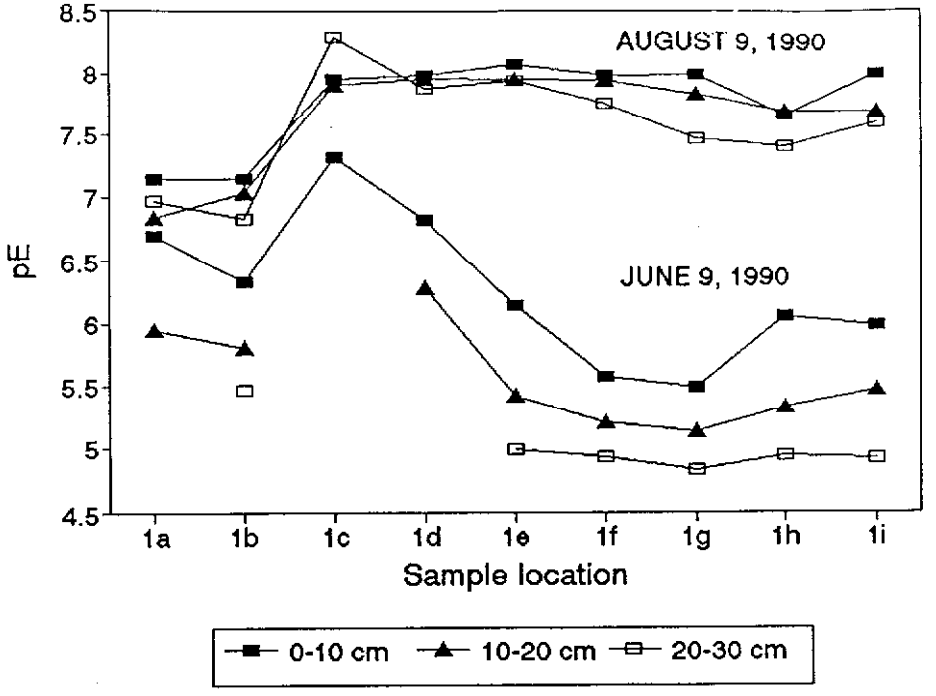


Figure 21: pE in Cell 1, Upper 30 cm, June 9, August 9, 1990.

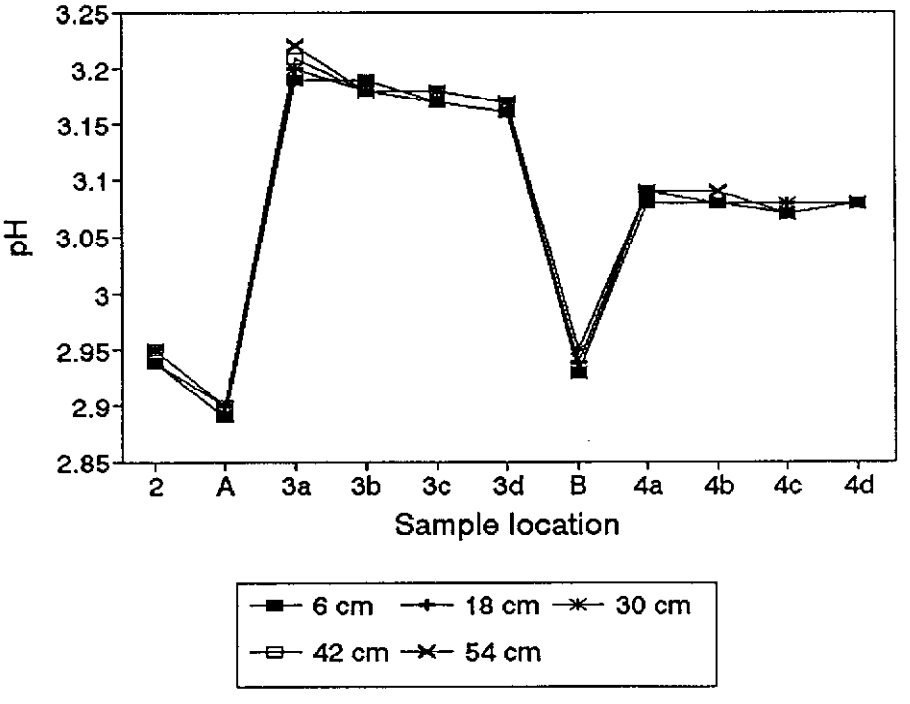


Figure 22: pH, Cell 2 to Cell 4d, Upper 54 cm, August 9, 1990

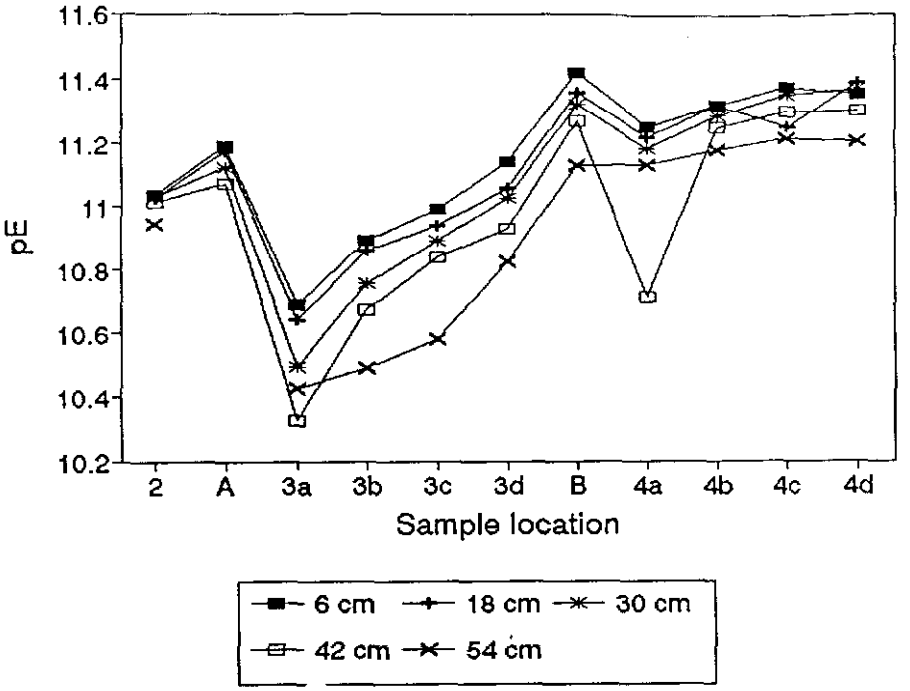


Figure 23: pE, Cell 2 to Cell 4d, Upper 54 cm, August 9, 1990.

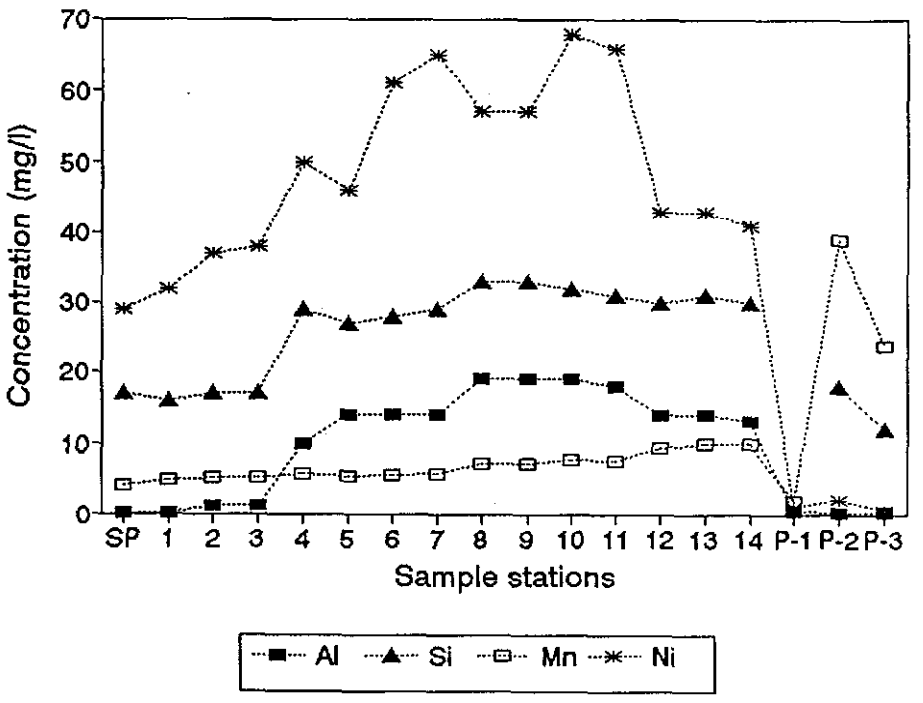


Figure 24: Concentration of Minor Ions in Cells, August 8, 1990.

3.3 Water chemistry in the Test Cell System.

The concentrations of selected elements (summer 1990 data) have been plotted against sample location on August 8, 1990 (Figures 24, 25 and 26). The ranges for each individual ion have been evaluated and the data are presented in Appendix 1 (Figures 19 - 33) for the period August 21, 1989 to March 28, 1990. The plots with the data for the summer of 1990 include the values for the particular element on September 28, 1989. This sampling point was included for ease of comparison of changes over time. It should be noted, however, that the 1989/90 water samples were not field filtered and preserved. This may account for some of the scatter in the data from this period.

From this data evaluation it can be concluded that, except for Na, K, and Fe, the concentration of all other ions increased in the summer of 1990. This is not too surprising if the accompanying drop in pH is considered. The concentrations throughout the cell system for each sample date remained more or less constant for Mg, Na, Ni, P, S, and Sr, with slight increases noted for Ca, K, Si, and Co, and significant increases for Al, Mn, Cu, and Zn. Decreasing concentrations are noted for the element Fe.

A comparison of the ion concentrations on the two sampling dates (July 18 and August 8, 1990) shows that Mg remained more or less constant, while Fe, K, Na, and Si decreased, and Al, Ca, Co, Cu, Mn, Ni, P, S, and Zn increased with time or with differences in pH and temperature of the water in the cell system.

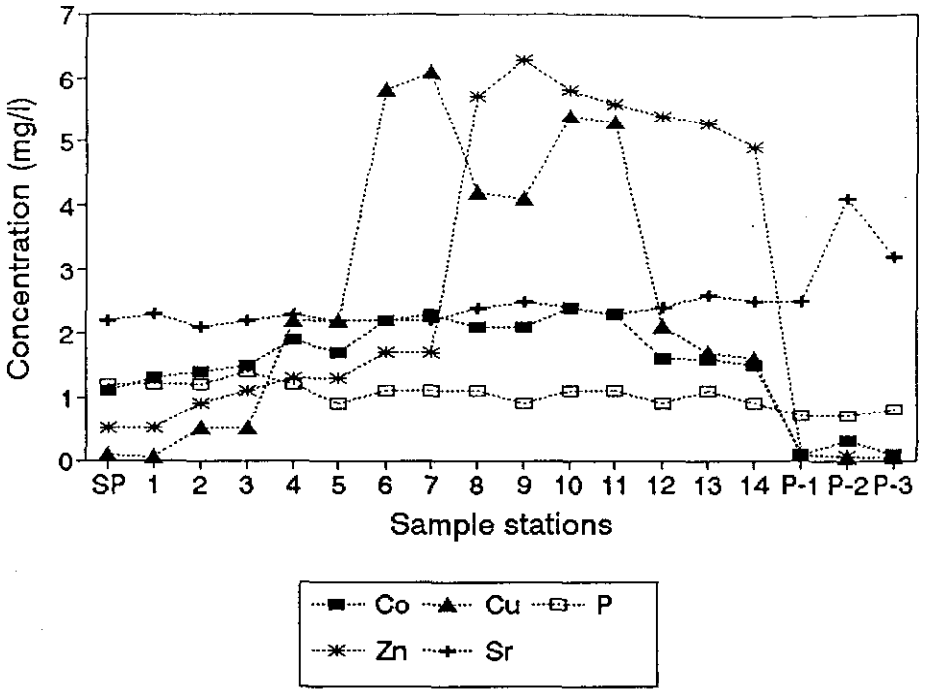


Figure 25: Concentration of Trace Ions in Cells, August 8, 1990.

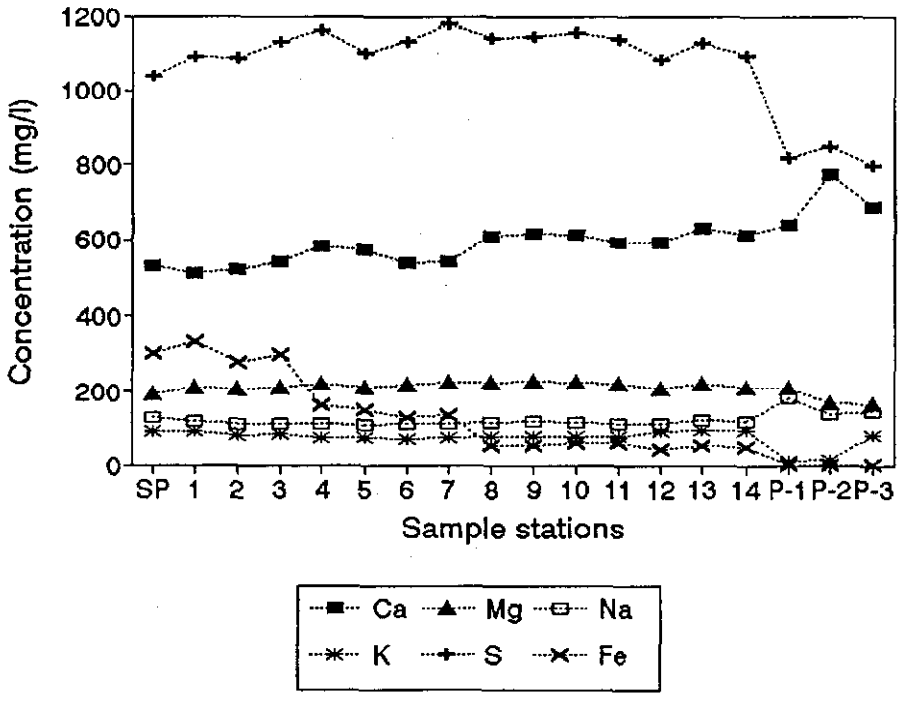


Figure 26: Concentration of Major Ions in Cells, August 8, 1990.

In order to evaluate the type and magnitude of changes within the cell system the percent difference in the ion concentration between adjoining sample stations was determined for each sample date. In addition the change with respect to July 18, 1990 was also calculated (Figures 34 to 40 in Appendix 1). When considering differences expressed as percentage, the error inherent in the analytical technique must also be taken into account. Analytical errors in the ICP analyses are less than 25% in 95% of the samples for those elements where concentrations are greater than 1 mg/L. Consideration of error is important when increases in the concentrations of Al, Co, Cu, P, and Zn are considered, as they could be due to the inherent variability of 25% in the analytical procedure. Of interest are the rather strong variations in [Ni] and [Si]. It appears that Ni and Si react, with different time lags, to seasonal decreases and increases in pH. It is also interesting to note that [Ni] decreased in the seepage, while it increased in the feed water (and the rest of the system). Possible explanations include: (1) Ni is being leached out of dam/dyke materials, and (2) Ni is being re-mobilized from precipitate in the cells and ponds. It is unlikely that increased [Ni] is derived from the discharge of ground water into the cells as discussed later in the next section.

3.3.1 Chemical changes due to interactions with cell walls materials

Changes in concentration are not restricted to the permeable berms and for most ions an equal or greater variation can be observed within the cells. The only elements which show a consistent significant change across all the berms for both sample dates are Al

and Fe, and to a lesser extent Si. Aluminium and silicon increase and iron decreases. Al and Si are most likely derived from dissolution of feldspars or other alumina-silicates. The loss of Fe is due to precipitation in the berms.

A closer examination of the data summarized in the Appendix 1 reveals that consistent trends are present for specific ion pairs on one of the two sample dates, but not on both dates. The ion pairs Co/Ni and Ca/S have similar sources (Ni-Co sulphide & gypsum) and display and almost identical trend for the ion pairs on one of the dates, but a much poorer correlation for the other date. This clearly indicates that different chemical equilibria and processes are operational for the ion pairs within the cell system on the two dates, which displayed a difference in the pH/pE conditions. Therefore it would be expected that different precipitation conditions exist.

A word of caution should be expressed at this time. Although the analytical data of the two complete sampling surveys show considerable difference, it should be realized that samples were taken with different sets of physical parameters operational within the cell system. Not only were the flow rates through the system different, but also the water levels within the cell system as discussed previously.

It is reasonable to assume that the cell walls are not chemically inert. The material used for building the dykes is clay-rich which will result in ion exchange. The rip rap placed as a protective cover on the dykes is not clean but contains, in places, considerable

amounts of sulphide minerals (pyrite, pyrrhotite, chalcopyrite, Ni-Co sulphides, etc.) in various stages of weathering.

In addition, all cells show a zone above the water level with considerable precipitation (primarily gypsum). Rising water levels will therefore bring the cell water in direct contact with weathered (sulphide) rock, precipitate, and ion exchange surfaces and will undoubtedly result in dissolution of precipitates and weathering products.

In summary, given the differences of the chemical equilibria, precipitation of different compounds may occur. It is therefore felt that the variability in the ion concentrations between consecutive stations on the same sampling date and between the two sampling dates, and the lack of consistent change for most ions is primarily caused by the interaction of cell water and the dykes.

3.4 Chemical Changes Due to Ground Water Discharge

As the Test Cell System is constructed at the foot of a tailings dam it can be expected that ground water will seep into the system. It is also possible that the cells may serve as a recharge area.

Flow measurements in the cells during early June 1990 indicated cumulative ground water discharge between Pond A and Cell 4 at a rate of approximately 1.4 L/min. Appreciable

ground water discharge could change the chemical environment within the cells. In order to better understand the interaction between the ground water and surface water flow systems, piezometers were installed. Details of the installation are given in the Appendix 1, along with the stratigraphy of the holes and completion details (Figures 1 - 9). Their location is shown in Schematic 1.

The cells are underlain predominantly by silt and clay, laminated to thinly bedded, and interbedded. In places thin beds of very fine-grained, well-sorted sand are present. The sediments are most likely of lacustrine origin. Two holes, P-5 & P-7 show the presence of considerable amounts of sand. In P-5 the sand sequence is intermixed with considerable amounts of organic (decayed plant matter) and clay. The sand sequence encountered in P-7 is a clean, well sorted, fine to medium grained sand. Rapid inflow of water during the augering prevented total penetration of this bed and the total thickness of the sand bed is therefore not known.

The hydraulic conductivity of the sediments was determined from slug tests, the results of which are given in Appendix 1 (Figures 10 to 18) and summarized in Figure 27. The magnitude of the hydraulic conductivities corresponds well with the type of sediment found in the shallow subsurface and the variability observed between holes.

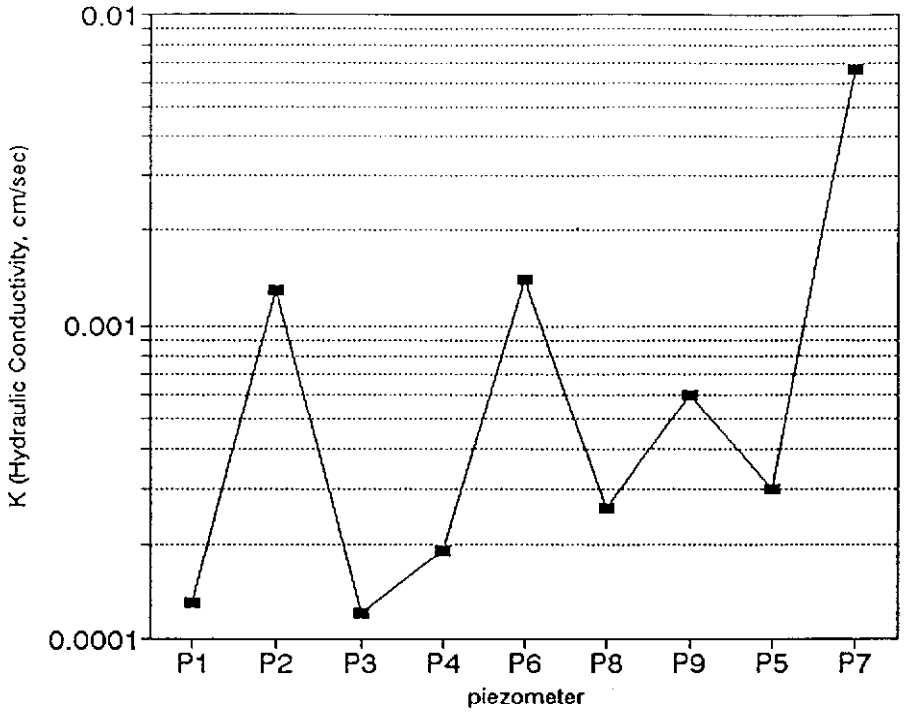


Figure 27: Hydraulic Conductivity Piezometers.

Water levels have been measured in the piezometers since April 24, 1990 and the results are plotted in Figure 28. Figure 28a shows the water levels in P-1, P-2, P-3, and P-6, while P-4, P-5, and P-7, located outside the cell system, are illustrated in Figure 28b. Water levels in P-8 & P-9, constructed in early August, 1990, are not plotted because the elevation of the structures has not been measured. Water levels in the piezometers and in the cell immediately adjacent to each piezometer are shown in Figures 29, 30, and 31. P-1, P-2, P-3, and P-6 closely follow the fluctuations of the water level in the cells (Figures 29a, 29b, 30a and 31a.).

P-6 showed a somewhat muted response once the water level in the cell became higher than the piezometer (Fig.31a). At this point in time Cell 2 became a potential recharge source to the ground water. The response of P-4, P-5, and P-7 to water level changes in the nearest cell (Figs. 30b and 31b) was essentially non-existent or very subdued at best. P-4 and P-5 showed a consistent gradual decline in the water level from April to early August. This may reflect changes of a more regional nature rather than those created by the immediate local cell environment. P-4, which was completed below P-5, showed a higher water level than P-5 (Fig.30b). This indicated an upward direction of ground water flow. P-7 showed a very uniform water level and did not respond to any changes in the Cell 1 water level. This piezometer was completed in an area characterized by considerable seepage. Although the piezometer would be classified as completed in a confined "aquifer" (i.e. sand overlain by clay and elevation of water level higher than top of the aquifer) lack of lateral confinement (extensive seepage) causes the "aquifer" to

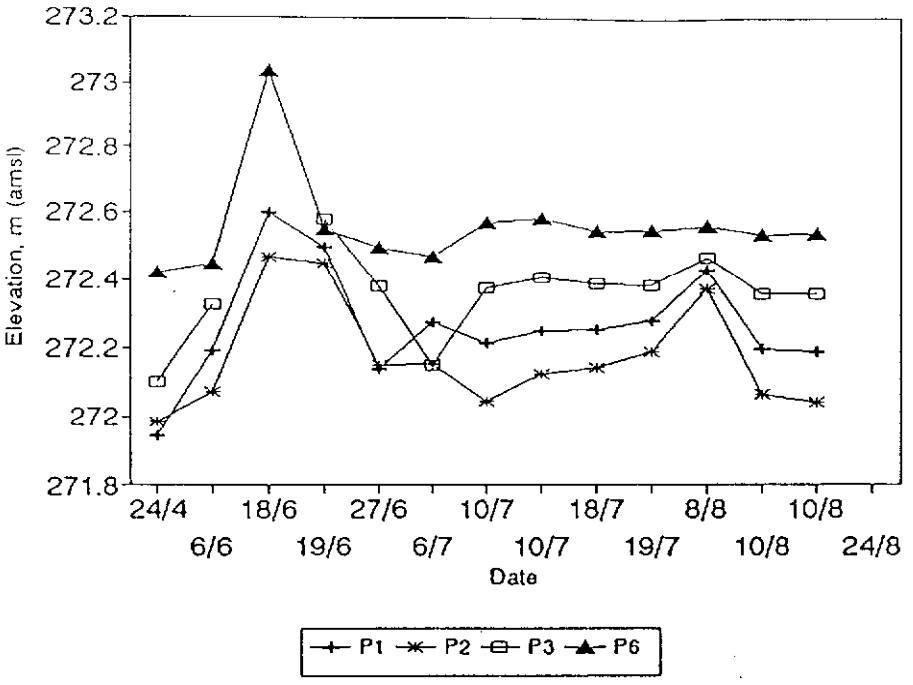


Figure 28a: Elevation of Water Levels in Piezometers: P-1, P-2, P-3 and P-6.

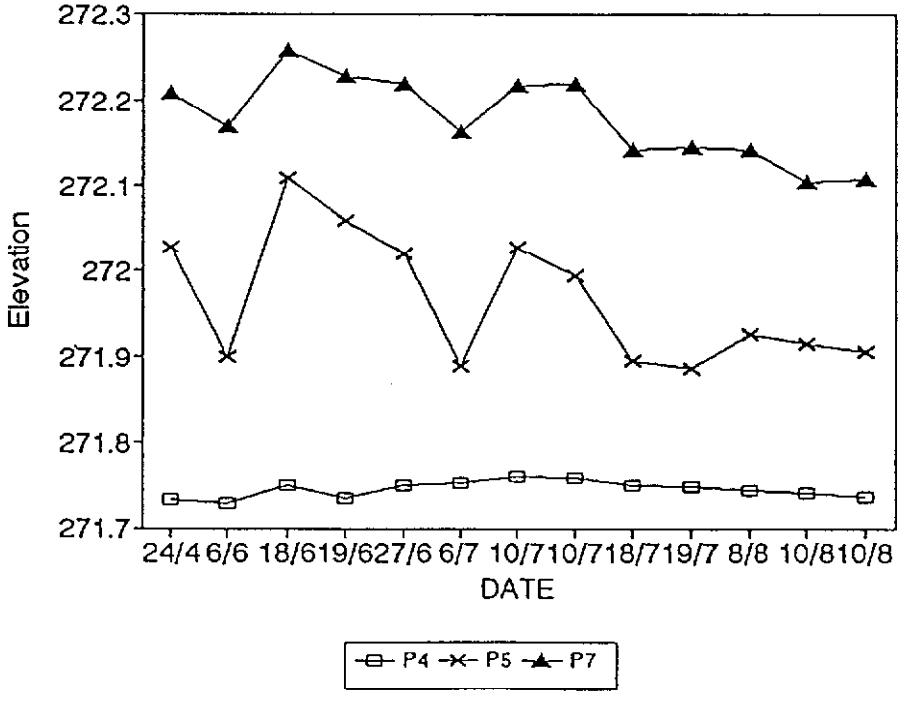


Figure 28b: Elevation of Water Levels in Piezometers: P-4, P-5 and P-7.

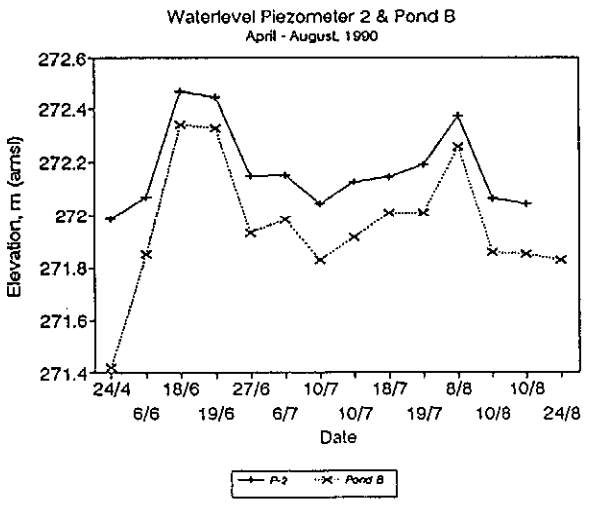


Figure 29b: Elevation of Water Levels in Piezometer P-2 and Pond B.

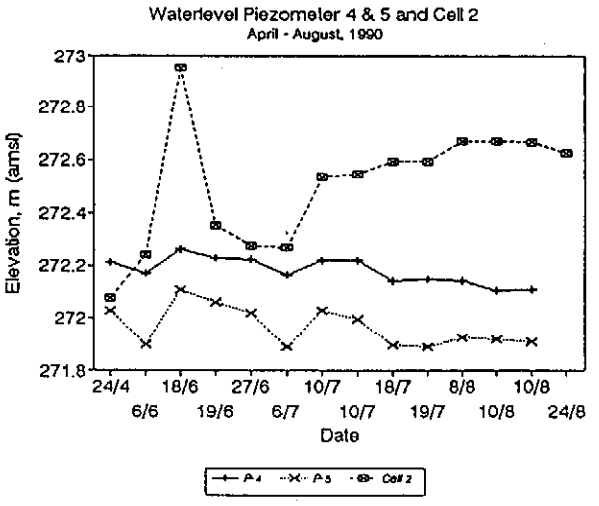


Figure 30b: Elevation of Water Levels in Piezometers P-4, P-5 and Cell 2.

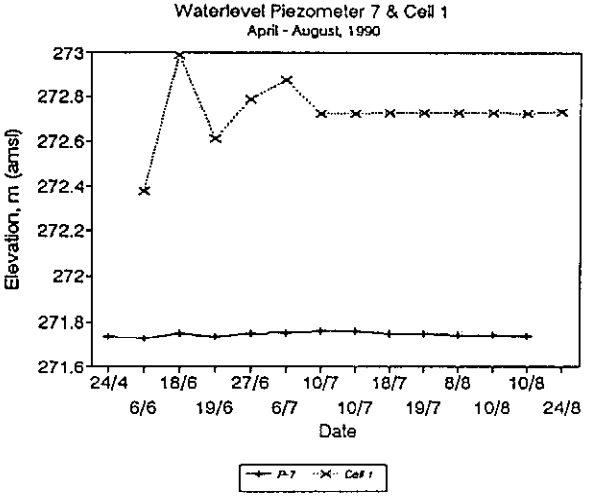


Figure 31b: Elevation of Water Levels in Piezometer P-7 and Cell 1.

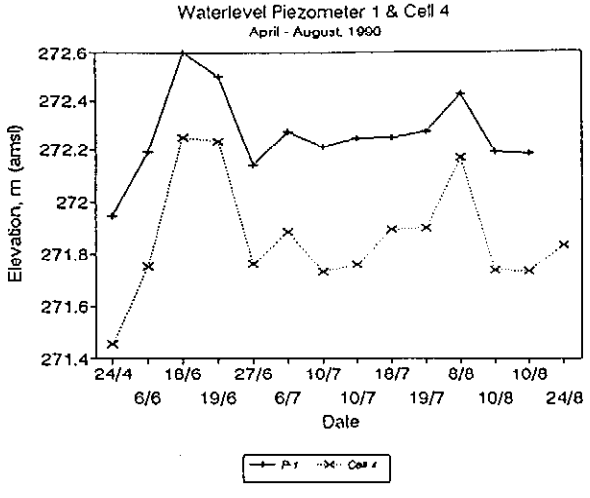


Figure 29a: Elevation of Water Levels in Piezometer P-1 and Cell 4.

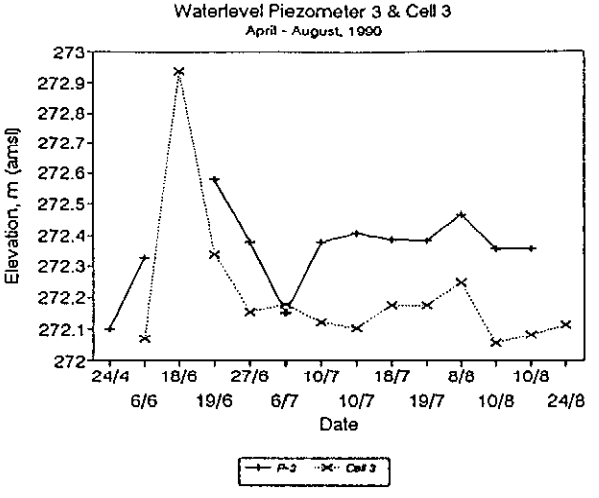


Figure 30a: Elevation of Water Levels in Piezometer P-3 and Cell 3.

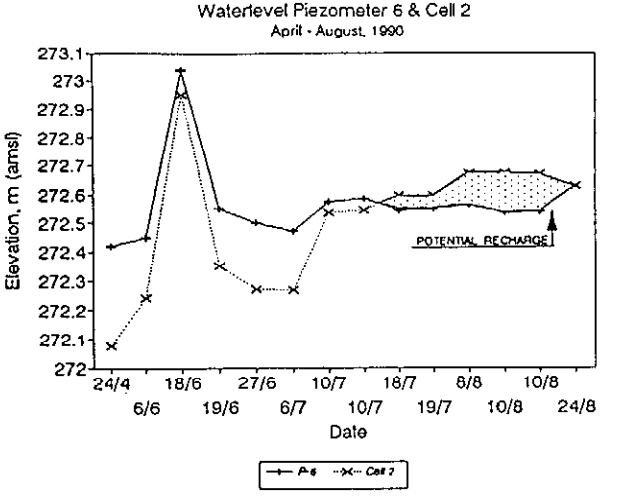


Figure 31a: Elevation of Water Levels in Piezometer P-6 and Cell 2.

behave as unconfined. It is obvious from the elevation of the water level in Cell 1 that this cell is a potential recharge source for the ground water.

The response of the piezometers to changes in the cell water levels displays two distinct trends in that P-1, P-2, P-3, and P-6 and their corresponding cells show a linear relationship with moderate scatter. P-4, P-5, and P-7, the piezometers below the cell system, showed no relationship as expected form the data discussed above.

The water levels in the piezometers completed in Cell 3, Pond B, and Cell 4 were consistently higher than levels in the cells. This indicates that a potential of ground water discharge into the cells is present. On the other hand, Cell 1 and 2 in all likelihood act as recharge sources to the ground water.

The hydraulic conductivities determined from the slug tests on the piezometers show a significant variability, which indicates a fairly complex geological model. This fact combined with the actual physical setting of the cell system precludes any simple solution to arrive at a rate of ground water discharge and/or recharge.

The low hydraulic conductivities of the sediments underlying the cell system, in combination with the results of the water chemistry data, seem to suggest however, that the rate of ground water discharge is relatively small under the operating conditions during the 1990 summer months.

Tables B-1 to B-3 in Appendix 1 present the analytical results for water samples from the piezometers. Figure 32 illustrates the variations in concentrations with time in each of the piezometers.

During the period covered by these analyses (early May to early August 1990), most of the piezometers, with the exception of P-1, P-5 and P-7, showed overall (seasonal?) decreases in the concentrations of S, Ca, Mg, Na, Mn, and Ni; and increases in the concentrations of K and Si. [S], [Ca], and [Na] increased somewhat in P-1, and [Ni] in P-5 (and P-7, if the questionable value of 91 mg/L is correct).

The most surprising aspect of the data are the differences in concentrations between individual piezometers, particularly for S, Ca, Na, and Mn. This is likely a reflection of variations, over short distances, in the lithology of the sediments in which the piezometers are installed. Small variations in clay content, for instance, could selectively affect the concentrations of various exchangeable ions.

Most of the piezometer waters had higher [Ca] and [Mn] than the seepage and feed water. Concentrations of these elements in the feed water have presumably been decreased as a result of early aeration. The chemical composition of the water from P-7 appears to reflect mixing of ground water with infiltration from Cell 1 and/or Cell 2 (see also the section on pH and Redox Potential). Lower pH values in P-5 and particularly in P-7 are accompanied by significantly higher [Fe] and [Ni].

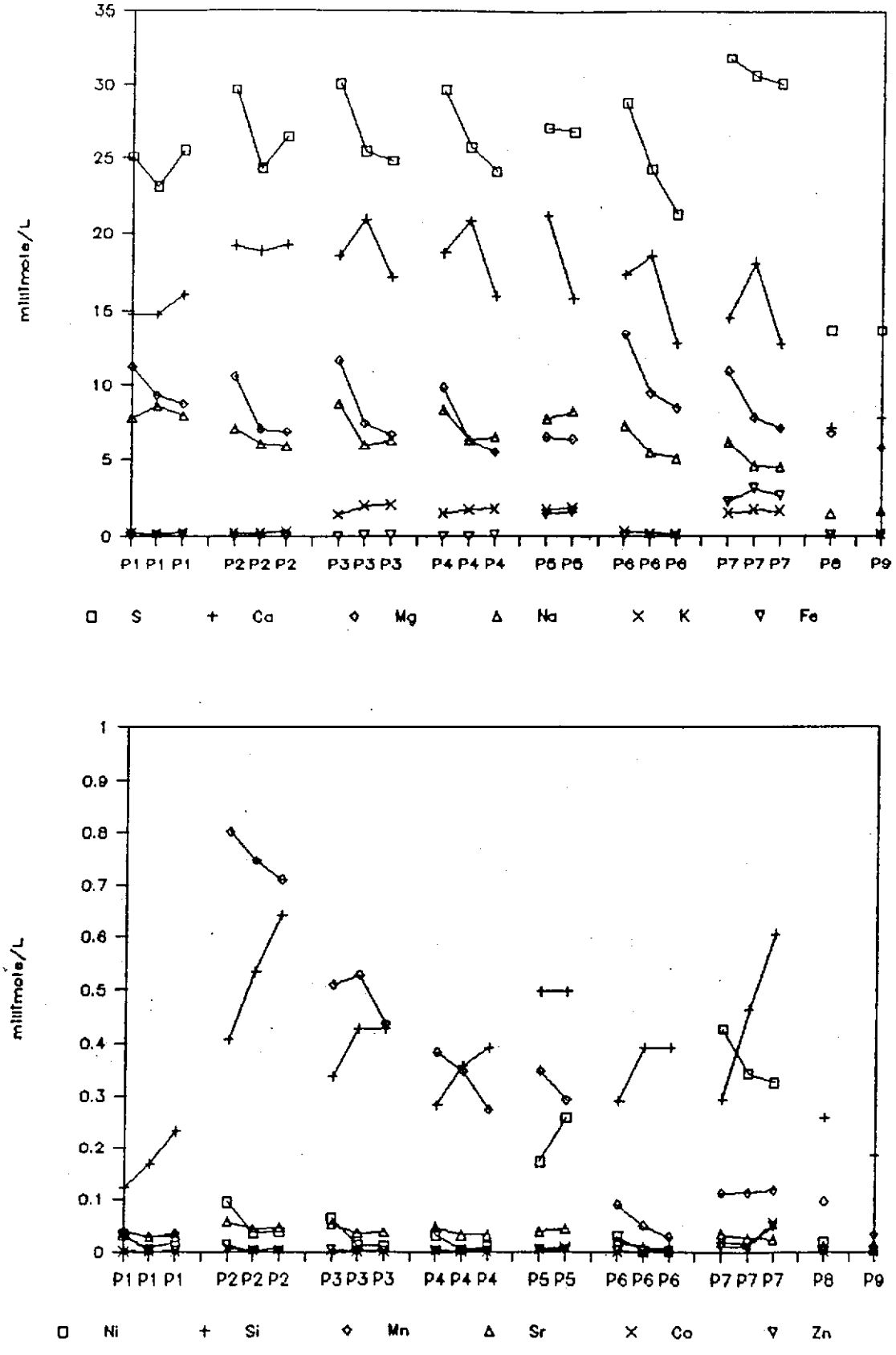


Figure 32: Makela Piezometers
Water Chemistry May, July, August 1990

3.5 Amendment and Seepage Water, Cells 3 and 4

The pH and pE profiles in Pond B and Cell 4 show little variation (Figures 22 and 23). There is no evidence of any effect of the amendment curtains in Cell 4. It should be mentioned that at the time these measurements were made the amendment curtains were submerged as the result of plugging of the outflow from Cell 4 by straw. This situation was corrected on August 10, 1990. During a later site visit (August 23/24, 1990) Eh measurements near the bottom of Cell 4 at location 4-c (Schematic 3) showed a drastic change in the Eh and pH. These drops could be the result of biological activity, ground water discharge or a combination of both.

Both Cell 3 and Cell 4 contain organic amendment curtains (Schematic 2). On July 18, 1990 each compartment was sampled to determine if the placement of the organic material had affected the chemistry of the water. The concentration in millimoles/L of all elements has been plotted and they are presented in Appendix 1. Slight changes can be noted for the ions through the cell but in essence the changes are within the analytical reproducibility. The same data analyses were carried out for Cell 4 which lead to identical conclusions.

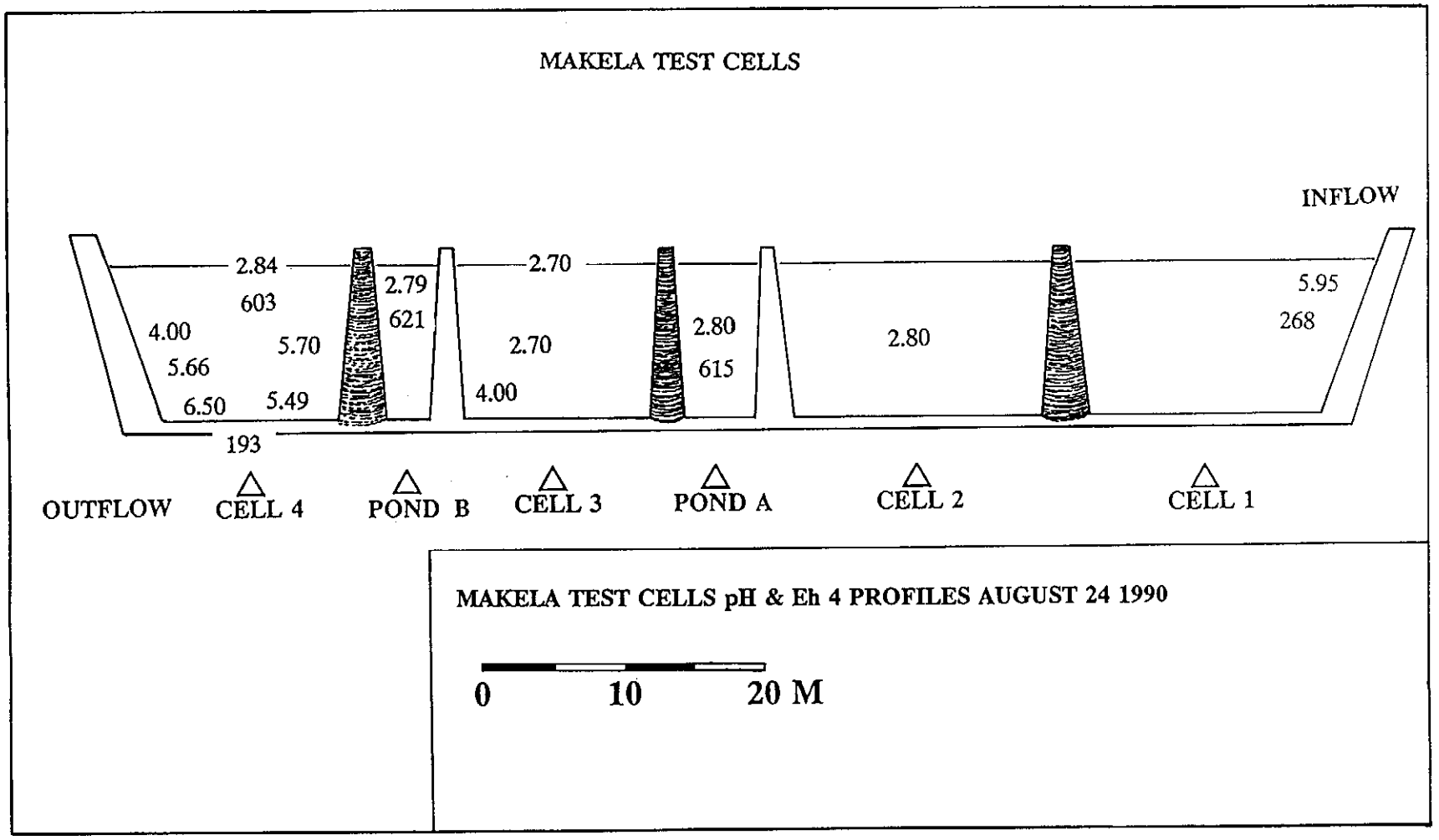
No signs of biological activity were found during the water sampling trips on July 18 and August 8, 1990. Eh values indicate total absence of reducing conditions in Cell 4. A survey of Cell 4, however, conducted during a field trip on August 23/24, 1990 showed significant changes in the pH in the lower part of the cell. The water in this zone had a

milky appearance. One Eh measurement on a bottom sample confirmed the likelihood of reducing conditions. The values of pH and Eh are given in Schematic 3 for this sampling date throughout the cell system (Figure 23).

It is well known that biological activity can readily create such conditions, but the ground water in the immediate vicinity is also in a reduced state. As was pointed out before, the potential of ground water discharge into Cell 4 exists and therefore the data have to be interpreted with caution.

The water chemistry of both the cell water and the ground water was therefore further evaluated. The data available for this review comprises water analyses for Station 12, 14 and piezometer P-1. Station 12 represents the inflow into cell 4, whereas Station 14 is the outflow from Cell 4 and the cell system.

The results for July 18 and August 8, 1990 are plotted in Figure 33a and 33b. As can be seen, the range of ionic concentrations is essentially the same for Stations 12 and 14. It is identical for August 8, 1990 and virtually identical for July 18, 1990. Al, P, Mn, and Cu (four elements out of fifteen) show a slight increase for Station 14. The increase in Mn and P cannot be accounted for by ground water discharge, because the concentration of these two elements is lower in both the ground water (P1) and the inflow into Cell 4 (Stn. 12).



Schematic 3: pH and Eh Profiles in Makela Test Cells
August 24, 1990

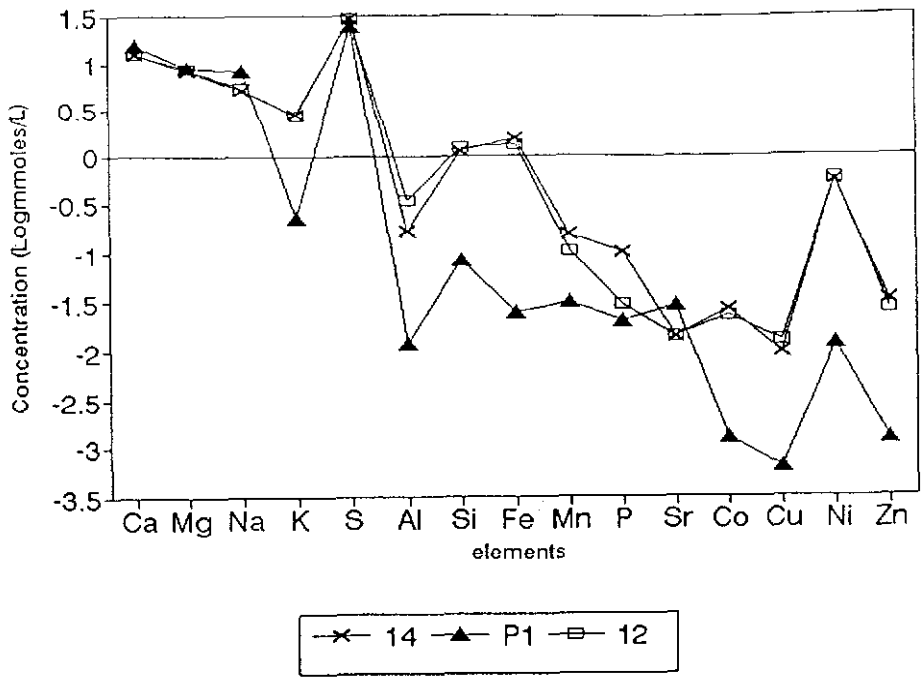


Figure 33a: Ion Concentration at STNs 12 and 14, and P-1, July 18, 1990

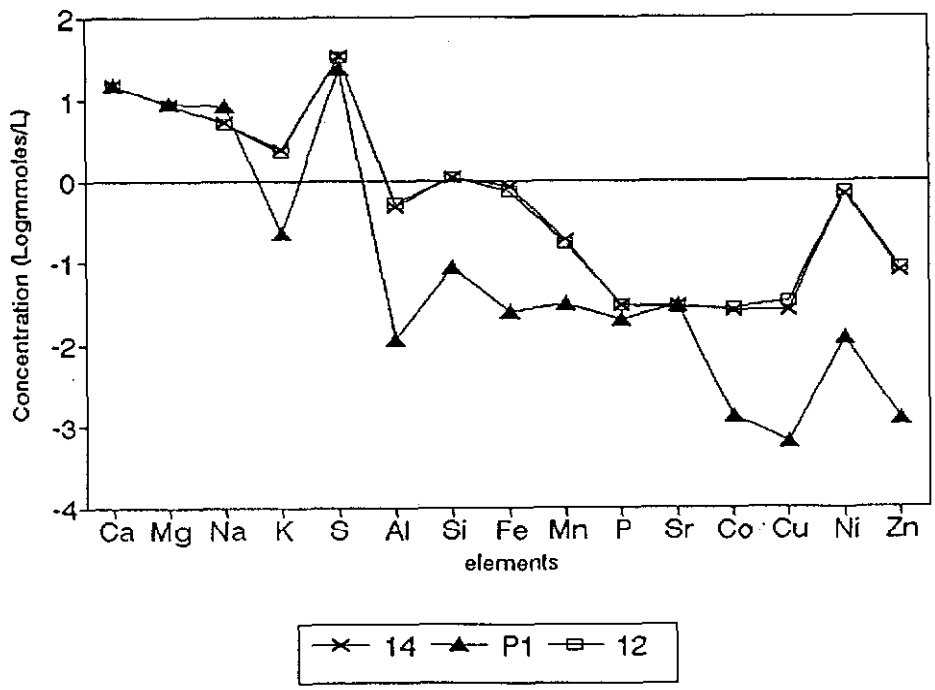


Figure 33b: Ion Concentration at STNs 12 and 14, and P-1, August 8, 1990

Furthermore, the composition of the ground water is sufficiently different from the cell water that ground water discharge would result in significant changes in the concentrations of several other elements, which would be readily seen in the water of Station 14. This is not the case as is obvious from the data for Cell 4. The results of the August 24, 1990 water samples for the bottom of Cell 4 and STN 14 illustrate major differences between the two water samples. Iron shows a considerable increase, while metal ions such as Ni, Co, Al, Zn and Cu show significant decreases (Figure 48b in appendix). Superimposing the results obtained in water samples at STN 14 collected on August 8 and 24, 1990, the water is essentially identical in composition and no evidence of mixing with groundwater can be found. Cell 4 "bottom" shows higher concentrations of Fe and Mn and lower concentrations of Al and Cu as compared to the cell outflow and the groundwater. On the other hand the concentration of K, Si, Co, Ni and Zn in the Cell 4 "bottom" water could readily be derived from mixing of groundwater and cell 4 water. The Eh of the cell "bottom" water is 60 mv.

No Eh measurements are available for P-1 on this date. The Eh in P-1 was 240 mV on June 9, and 380 mV on August 8, 1990. Although these values are higher than the cell "bottom" water, they also indicate that the Eh in the ground water can change significantly. The pH of the ground water in the vicinity of Cell 4 is about 6.5 (Figure 2) and very similar to the cell "bottom" water. pH measurements at the surface in Cell 4 on August 24, 1990 are consistently low and show no evidence of mixing, and the only vertical profile shows a relatively sudden increase between depths of 30 and 40 cm (Schematic 3). The distribution of the pH could be explained by a slow displacement of

cell water with colder ground water and sheet flow of warmer surface water through the cell. To replace the volume of "milky" water in the bottom of Cell 4 over a time period of 14 days (Aug.10-24) would have required a ground water discharge rate of at least 2 L/min, which in turn, would have increased the outflow from Cell 4.

No evidence of a rate increase in the outflow was found on August 24, 1990. It appears, therefore, that the observed change in the chemistry cannot be solely due to ground water discharge. Biological activity or a combination of biological activity and ground water discharge in all likelihood caused the observed changes in the water chemistry. These data represent the first indications that scale-up from enclosed to open systems may be possible.

4.0 ARUM MICROBIAL ECOLOGY

In this project the investigation of the microbial ecology of alkalinity-generation is approached pragmatically through empirical experiments both in the field and laboratory. The interaction between the population dynamics of the microbial community and the microhabitat, and in turn, the subsequent effect of these changes upon the population dynamics, renders any identifiable controlling factor empirical. Should the reader need evidence for this statement he/she is referred to Ehrlich (l990) and Zehnder (1988).

The investigation of the ARUM process considers the microbial communities colonizing various mixtures of organic amendments as black boxes, which mediate oxidation and reduction reactions. These reactions are accompanied by either loss (oxidation) or gain of electrons (reduction).

The rationale for the black box approach can be easily derived from Table 9 (Zehnder, l988, pages 17 and 18, Tables 1.4A and 1.4B). These reactions are only those of anaerobic components which are likely involved with alkalinity-generation. The aerobic decomposition, i.e. the steps required to break down the organic amendments to the usable units such as sugars, volatile fatty acids and alcohols, require a similar complementary set of microbial reactions. A simplified version of the microbial processes involved in ARUM is shown in Schematic 4. This schematic serves as a framework, within

TABLE 1.4A Reduction and oxidation reactions that may be combined to result in biologically mediated exergonic processes (pH 7), according to Stumm and Morgan (35)[a]

Reduction	$p\epsilon^\circ$ (pH = 7) log K (pH = 7)	Oxidation	$p\epsilon^\circ$ (pH = 7) − log K (pH = 7)
(A) $\frac{1}{4}O_2(g) + H^+(pH) + e = \frac{1}{2}H_2O$	+13.75	(L) $\frac{1}{8}CH_2O + \frac{1}{4}H_2O = \frac{1}{8}CO_2(g) + H^+(pH) + e$	−8.20
(B) $\frac{1}{5}NO_3^- + \frac{6}{5}H^+(pH) + e = \frac{1}{10}N_2(g) + \frac{3}{5}H_2O$	+12.65	(L-1) $\frac{1}{2}HCOO^- = \frac{1}{2}CO_2(g) + \frac{1}{2}H^+(pH) + e$	−8.73
(C) $\frac{1}{2}MnO_2(s) + \frac{1}{2}HCO_3^-(10^{-3}) + \frac{3}{2}H^+(pH) + e = \frac{1}{2}MnCO_3(s) + H_2O$	+8.9	(L-2) $\frac{1}{2}CH_2O + \frac{1}{2}H_2O = \frac{1}{2}HCOO^- + \frac{3}{2}H^+(pH) + e$	−7.68
(D) $\frac{1}{8}NO_3^- + \frac{5}{4}H^+(pH) + e = \frac{1}{8}NH_4^+ + \frac{3}{8}H_2O$	+6.15	(L-3) $\frac{1}{2}CH_3OH = \frac{1}{2}CH_2O + H^+(pH) + e$	−3.01
(E) $FeOOH(s) + HCO_3^-(10^{-3}) + 2H^+(pH) + e = FeCO_3(s) + 2H_2O$	−0.8	(L-4) $\frac{1}{2}CH_4(g) + \frac{1}{2}H_2O = \frac{1}{2}CH_3OH + H^+(pH) + e$	+2.88
(F) $\frac{1}{2}CH_2O + H^+(pH) + e = \frac{1}{2}CH_3OH$	−3.01	(M) $\frac{1}{8}HS^- + \frac{1}{2}H_2O = \frac{1}{8}SO_4^{2-} + \frac{9}{8}H^+(pH) + e$	−3.75
(G) $\frac{1}{8}SO_4^{2-} + \frac{9}{8}H^+(pH) + e = \frac{1}{8}HS^- + \frac{1}{2}H_2O$	−3.75	(N) $FeCO_3(s) + 2H_2O = FeOOH(s) + HCO_3^-(10^{-3}) + 2H^+(pH) + e$	−0.8
(H) $\frac{1}{8}CO_2(g) + H^+(pH) + e = \frac{1}{8}CH_4(g) + \frac{1}{4}H_2O$	−4.13	(O) $\frac{1}{8}NH_4^+ + \frac{3}{8}H_2O = \frac{1}{8}NO_3^- + \frac{5}{4}H^+(pH) + e$	+6.16
(J) $\frac{1}{6}N_2 + \frac{4}{3}H^+(pH) + e = \frac{1}{3}NH_4^+$	−4.68	(P) $\frac{1}{2}MnCO_3(s) + H_2O = \frac{1}{2}MnO_2(s) + \frac{1}{2}HCO_3^-(10^{-3}) + \frac{3}{2}H^+(pH) + e$	+8.9

[a]In this table the standard free energy of formation of CH_2O is the same as for dissolved unhydrolyzed formaldehyde.

TABLE 1.4B Combination of appropriate oxidation and reduction processes giving the more important redox processes mediated by bacteria[a]

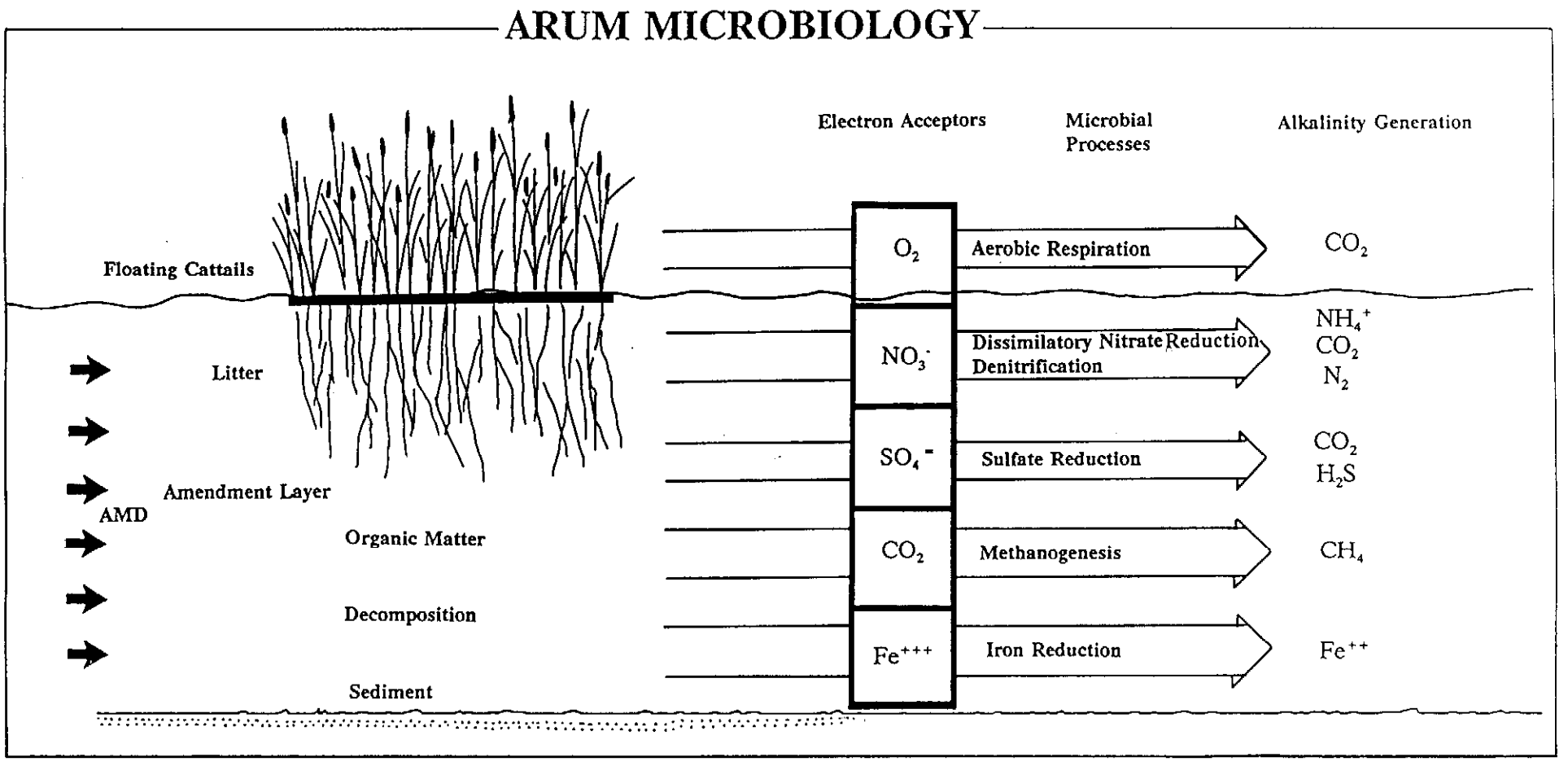
Examples	Combination	$-\Delta G^\circ$ kJ/equiv
Aerobic respiration	(A) + (L)	125.1
Denitrification	(B) + (L)	118.8
Nitrate reduction	(D) + (L)	81.8
Fermentation	(F) + (L)	29.6
Sulfate reduction	(G) + (L)	25.4
Methane fermentation	(H) + (L)	23.2
N Fixation	(J) + (L)	20.1
Sulfide oxidation	(A) + (M)	99.8
Nitrification	(A) + (O)	43.3
Ferrous oxidation	(A) + (N)	82.9
Mn(II) oxidation	(A) + (P)	27.7

[a]All calculations were done for the exchange of one electron.

Table 9: Anaerobic redox reactions

which the investigations carried out to date can be placed. It also identifies some of the essential components of the microbial community which deserve attention. The development of the ARUM process has been mainly conducted in the field in test cells at Makela with amendment curtains, and in the Straw Pond at the Denison (Stanrock) tailings, with an amendment blanket. At both sites, tests are carried out in 170 L ARUMators, and at the Makela site, in one ARUMator containing approx. 2,300 L (inner sleeve). Microbiological laboratory studies are carried out in small vials and in 1.5 L flow-through reactors at Dearborn Chemical Company Limited. This report covers the work period from April 1990 to December 1990 and reports on studies which have continued since the first report (Kalin 1990).

Previous studies have established that ARUM can be established in the laboratory in flow-through reactors (1.5 L capacity, flow rates of 100 mL/day). Alkalinity was generated in the batch scale-up ARUMators in the field. The results of the batch scale-up ARUMators are presented in Section 4.1, followed by the results of flow-through experiments in the laboratory in Section 4.2. Mechanisms of alkalinity-generation are addressed in Section 4.3, based on continuing amendment studies. Decomposition or availability of organic compounds is considered one of the limiting factors to the ARUM process and is addressed in Section 4.4. Materials and methods used in this section are either described in the first report or are given in detail in Appendix 2.



Schematic 4: Simplified ARUM Microbial ecosystem

4.1 Batch Field ARUMators

The 170 L ARUMators served two functions; first, as a monitoring device for the microbial alkalinity-generation and secondly, to produce 'microbial seed' for an eventual scale-up. This scale-up (pond or test cell) is expected to treat AMD either in batches or by controlled flow through the pond.

In Figure 34a to 34e microbial alkalinity-generation is presented as it develops with time in the four 170 L drum ARUMators (1, 2, A and B) and the 2,300 L ARUMator #3. ARUMators 1 and 2 were filled with seepage water from the Makela tailings dam in October l989. The concentration of heavy metals to be removed by alkalinity-generation was 96 mg/L for ARUMator 1, and 74 mg/L for ARUMator 2. ARUMator 3 was filled with seepage water which contained even higher nickel concentrations, 180 mg/L. The initial sampling of the ARUMators after 8 months indicated that some reduction of acidity had taken place in the top portion of the ARUMators. Essentially no alkalinity had been generated up to June l990 in ARUMators 1 and 2 (Figure 34a and 34b). One month later, however, in July, alkalinity values were in the same range as those of acidity and by October (1990) significant concentrations of alkalinity were present with essentially no acidity left in the water.

In Figure 34c, the results from ARUMator 3 are plotted. The onset of alkalinity-generation was delayed, but after one year a significant reduction of acidity from an average of about 1500 mg $CaCO_3$/L to 600 mg/L occurred throughout the inner sleeve of the tank. The

inner sleeve was opened on November 22 and the entire tank was filled with AMD, testing the first batch conditions. The total volume of the inner and outer sleeved ARUMator is 3,200 L.

ARUMators A and B, upon installation, were filled with seepage water from Denison (Stanrock) uranium tailings in May 1990. The seepage water did not contain significant concentrations of potentially toxic heavy metals, such as nickel or copper. In Figure 34d and 34e the alkalinity-generation in these ARUMators is depicted. Although the absolute values of acidity are in the same order of magnitude as those of the ARUMators filled with Makela seepage water, the onset of alkalinity-generation is slower. By the end of the measurement period, however, acidity was reduced and replaced by equal quantities of alkalinity throughout the 170 L drums.

The composition of gases in the headspace of the ARUMators was monitored over the summer of 1990 by use of Dräger tubes. This gives an indication of which microbial groups are most active. Carbon dioxide concentration gives an indication of overall microbial activity; methane an indication of methanogen activity; and hydrogen sulphide an indication of sulphate reducer activity. The latter are believed to be important contributors to alkalinity-generation. The data are summarized in Table 10.

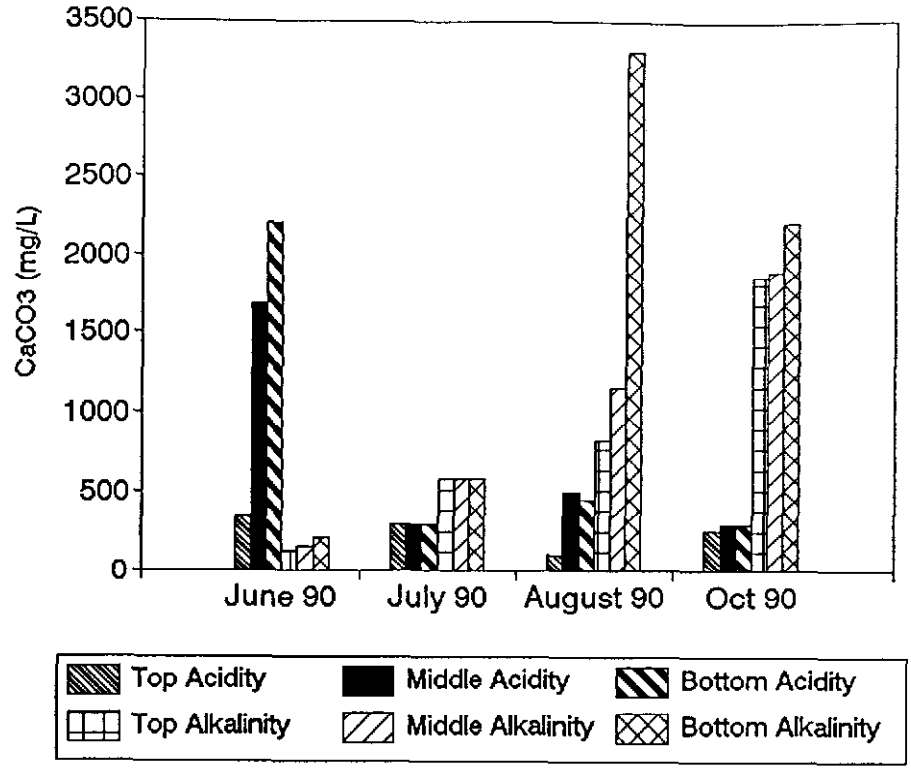


Figure 34a: Microbial Acidity/Alkalinity Generation in Makela ARUMator 1

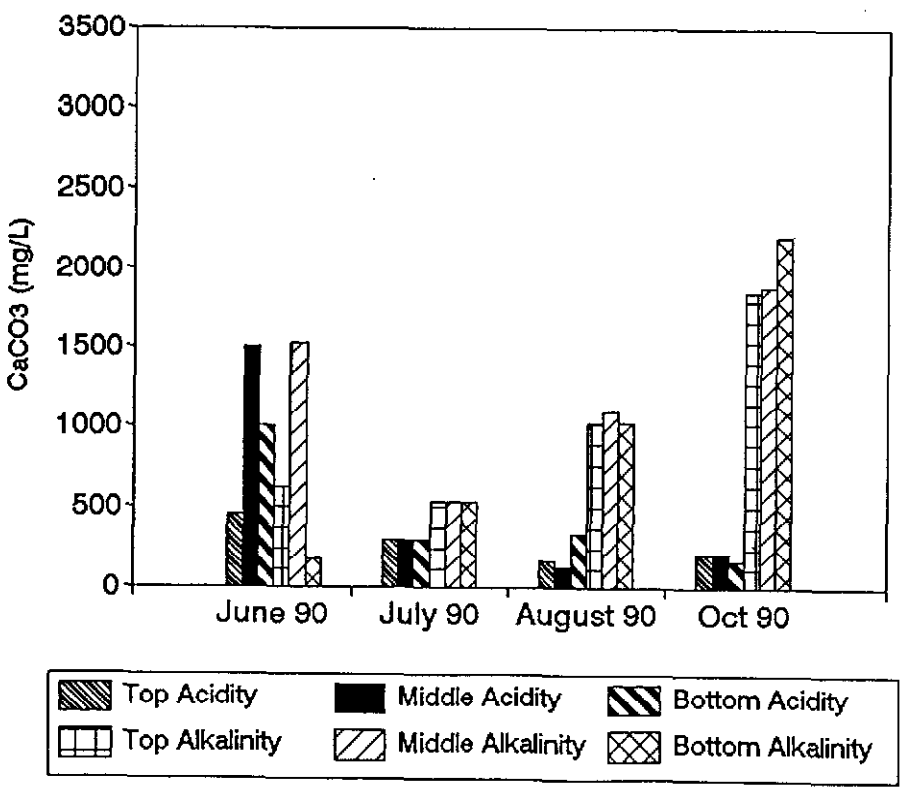


Figure 34b: Microbial Acidity/Alkalinity Generation in Makela ARUMator 2

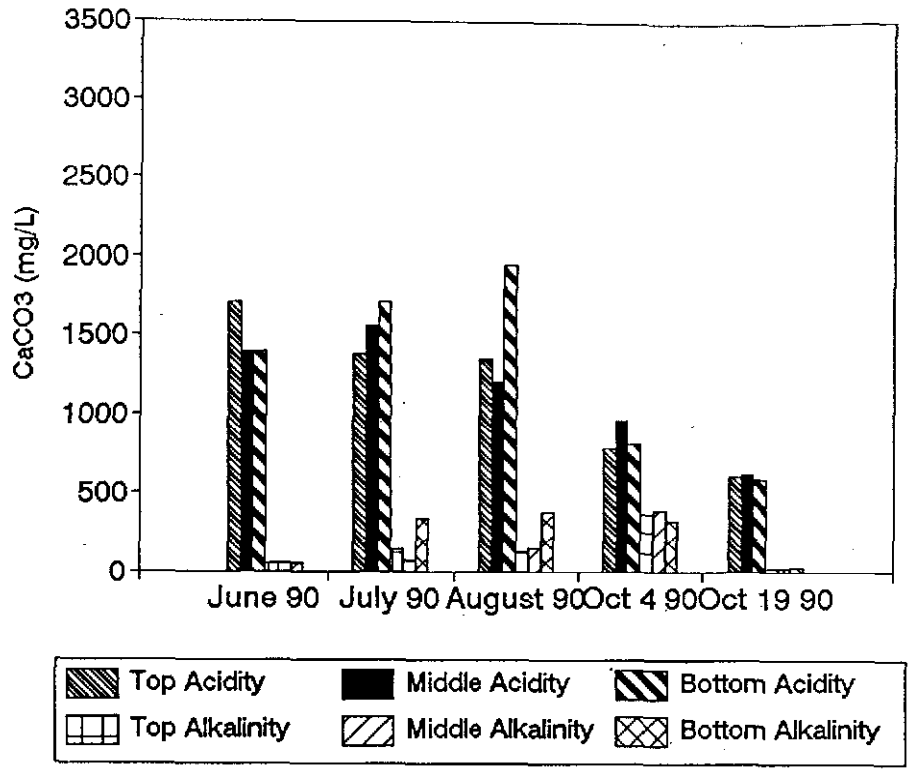


Figure 34c: Microbial Acidity/Alkalinity Generation in Makela ARUMator 3

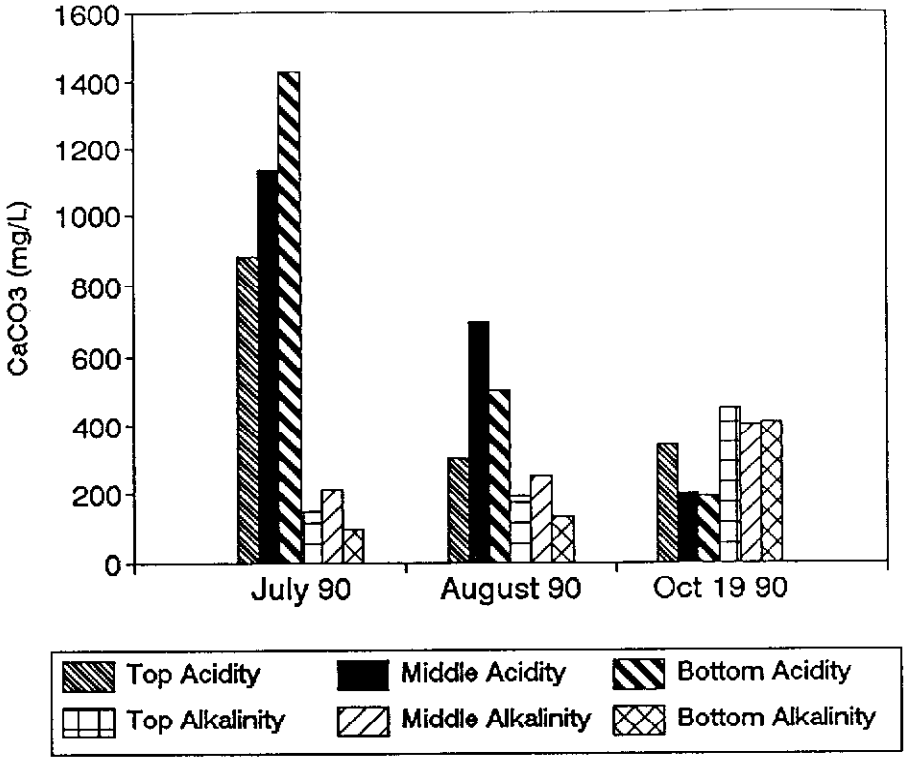


Figure 34d: Microbial Acidity/Alkalinity Generation in Denison ARUMator A with seepages from uranium tailings

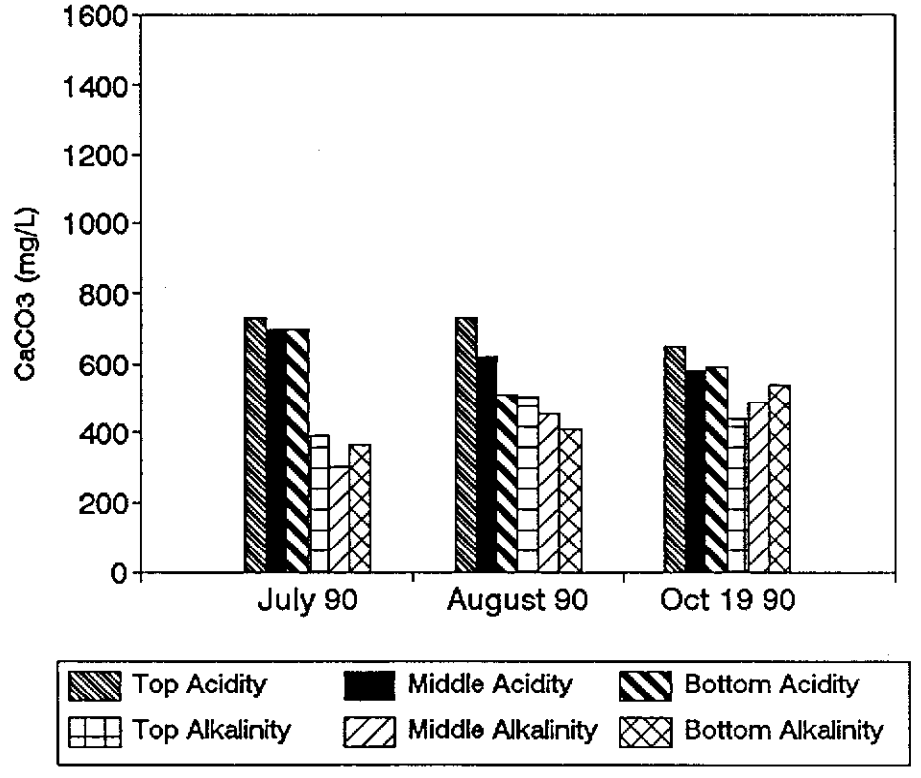


Figure 34e: Microbial Acidity/Alkalinity Generation in Denison ARUMator B with seepages from uranium tailings

In Denison (Stanrock) ARUMators A and B, carbon dioxide concentration increased from 0.2% and <0.2% to 1.0% and 0.4% respectively between the 2 sampling dates (June 7 and July 7) indicating a substantial increase in microbial activity over this period. The differences between the two ARUMators may be due to differences in their leakiness rather than differences in microbial activity. Assuming that the ARUMators are functioning properly, no hydrogen sulphide should be measured in the headspace, as it is expected that it should all precipitate with the metals. After the redox potential has reached a low value, methane should be detected, as was the case in October in ARUMator B at Denison.

In Makela ARUMators 1 and 3, increases in carbon dioxide concentrations were observed between July 18 and August 10, but not between August 10 and September 5. The carbon dioxide concentration (up to 5%) suggests high microbial activity. As at Denison, hydrogen sulphide was not detected but methane was detected on August 10, 1990. Water samples were collected from ARUMators three times for analysis, in early June, early July, and early August 1990.

DATE	ARUMATOR	CARBON DIOXIDE	HYDROGEN SULPHIDE	METHANE
	DENISON			
07/06/90	A	0.2 %	ND	ND
	B	ND	ND	-
07/07 90	A	1 %	ND	ND
	B	0.4 %	ND	ND
17/07/90	A	1.6 %	ND	ND
	B	1.2 %	ND	ND
21/08/90	A	-	ND	ND
	B	-	ND	PR
18/10/90	A	0.15 %	ND	ND
	B	0.5 %	ND	PR
	MAKELA			
18/07/90	1	1.4 %	ND	ND
	3	2.2 %	ND	ND
10/08/90	1	3 %	ND	ND
	2	5 %	ND	ND
	3	0.2 %	ND	ND
5/10/90	1	3 %	ND	ND
	2	2 %	ND	ND
	3	2 %	ND	ND

ND - none detected
PR - present

Table 10: Gas Headspace Monitoring Drager Tubes

Results of the analyses of the ARUMator samples, together with the results of various field measurements, are given in Tables C-1 to C-3 in Appendix 1. Acidity titration curves have been discussed in a previous section (Figure 1) for the three Makela ARUMators. No further detailed analysis has been carried out on the Denison ARUMators to date, due to the interferences with the organic as discussed in Section 2.

In Figure 35, the elemental composition of the Makela ARUMators is analyzed. ARUMator #1 showed increases in all the concentrations from top to bottom in June. The homogenized sample taken in July indicated a drop in the 'average' concentrations of Fe, Ni, Co, and Zn. The August samples showed slight increases in most concentrations, except [S] and [Zn]. Relative to the surrounding cell waters, final concentrations of S, Fe, Ni, Co, Zn, and Si were lower, while [K] was higher. Higher [K] are probably the result of organic amendment losses.

ARUMator #2 showed increases in all the concentrations from top to bottom in June. The homogenized sample taken in July indicated a drop in the 'average' concentrations of Fe, Ni, Co, and Zn. The August samples showed increases in all concentrations from top to bottom, except [S] which decreased. Compared to the July sample, the August

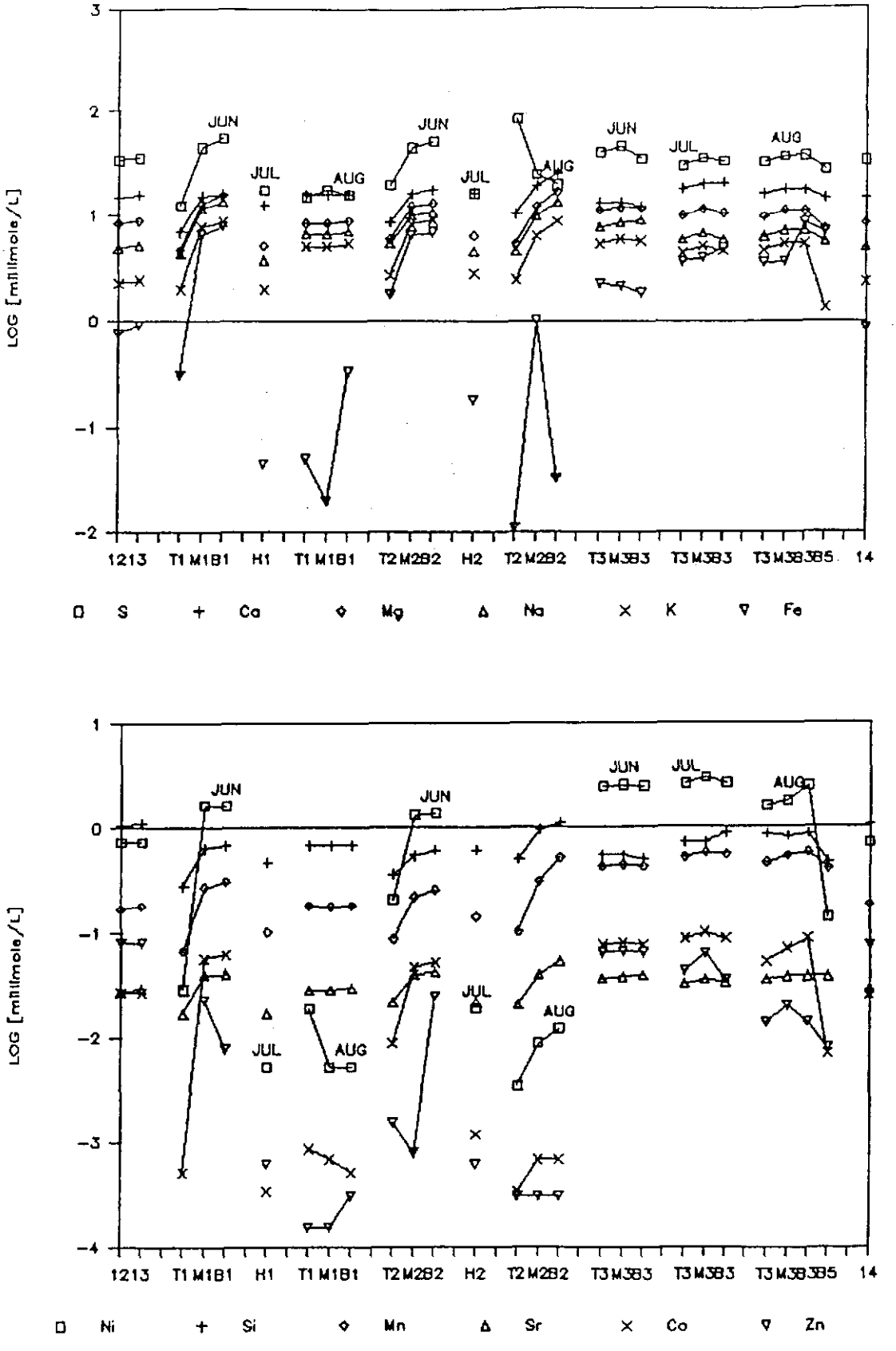


Figure 35: ARUM Chemistry - June, August, 1990

samples showed some increases in most concentrations, but [Ni], [Co], and [Zn] dropped even further. Relative to the surrounding cell waters, final concentrations were similar to those in ARUMator #1. ARUMator #3 showed only small variations in concentrations from top to bottom. Compared to June samples, July and August samples showed small increases in [Ca], [Fe], [Mn], and [Si], and a decrease in [Zn]. Relative to the surrounding cell waters, the final concentrations of Ca, Mg, Na, and Sr were slightly higher; concentrations of Fe, Ni, Co, Mn, and K were noticeably higher, while [Si] and [Zn] were lower.

The variations in the concentrations of heavy metals are presumably related to the variations in pH and redox potential discussed previously.

In summary, the samples from ARUMators #1 and #2 had generally higher pH and lower pE, [Fe], [Ni], [Co], and [Zn] than cell waters. Samples from ARUMator #3 had lower pH and [Zn], and higher [Fe], [Ni], [Co], and [Mn] than cell waters. Sample pE was somewhat higher than for other ARUMators.

The titration curves (Figure 1) suggest that some generation of alkalinity did take place in the ARUMators, and that ARUMator #3 was the least effective in this respect.

The Eh and pH conditions in ARUMators #1 and #2 were suitable for the occurrence of supersaturation with respect to several metal-sulphides. As discussed in Section 3.2.3, supersaturation was indicated for at least some of the ARUMator samples, with respect

to: pyrite, Cu-metal, cuprite, chalcosite (djurleite/ anilite/ blaublei) and covellite, chalcopyrite, sphalerite, otavite, greenockite, and galena.

4.2 Laboratory Flow Experiments with AMD from Makela and Denison

Makela flow experiment I : In order to raise the pH from 2.5 to 4, the level at which sulphate-reducing bacteria can thrive, the acidity of seepage water must be reduced. Figure 36 demonstrates that Denison water requires about 10 x the amount of alkalinity-generation required by Makela seepage water. This alkalinity can be generated by bacterial populations in batch reactors as described above. To extend these results, flow-through reactors were constructed in the laboratory to test alkalinity-generation at different flow rates. Figure 37 shows the results of a flow experiment which was continued from an experiment reported in June 1990. The influent entered the reactor from the top, and exited from the bottom of the reactor at 100 mL/day. Reactor #3, used previously, had recovered from an excessive flow rate of 500 mL/day. At 100 mL/day, the ARUM process continued for 57 days. The bottom region of the reactor remained black. Sulphate concentrations in the effluent decreased a little during the 57 days of operation. Nickel concentrations in the effluent were reduced to non-detectable limits (<0.2 mg/L) except for 5 sampling periods. The reappearance of detectable amounts of nickel in the reactor effluents coincided with a decrease in pH and increases in

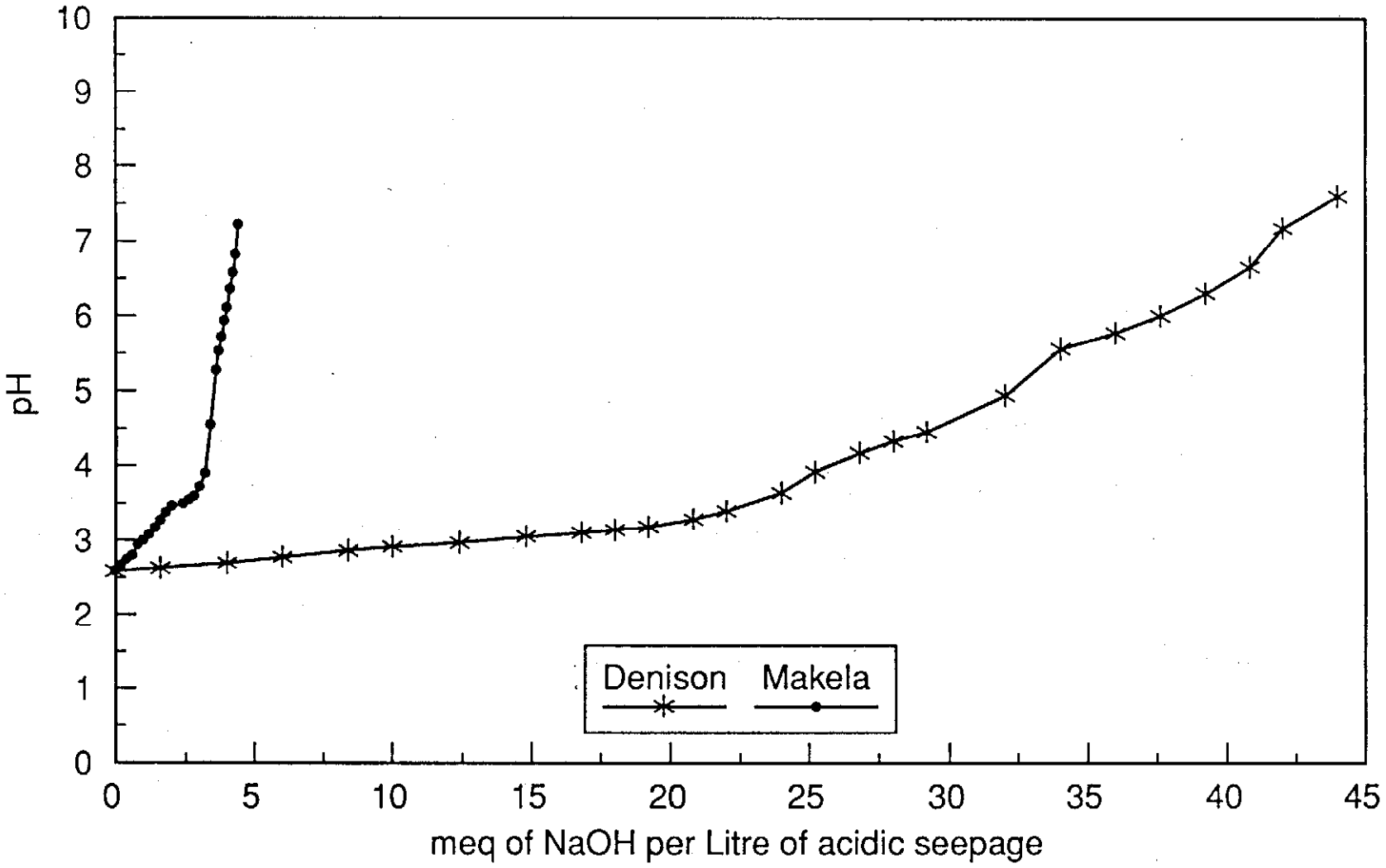


Figure 36: Neutralization of Seepage Water Titration Curve

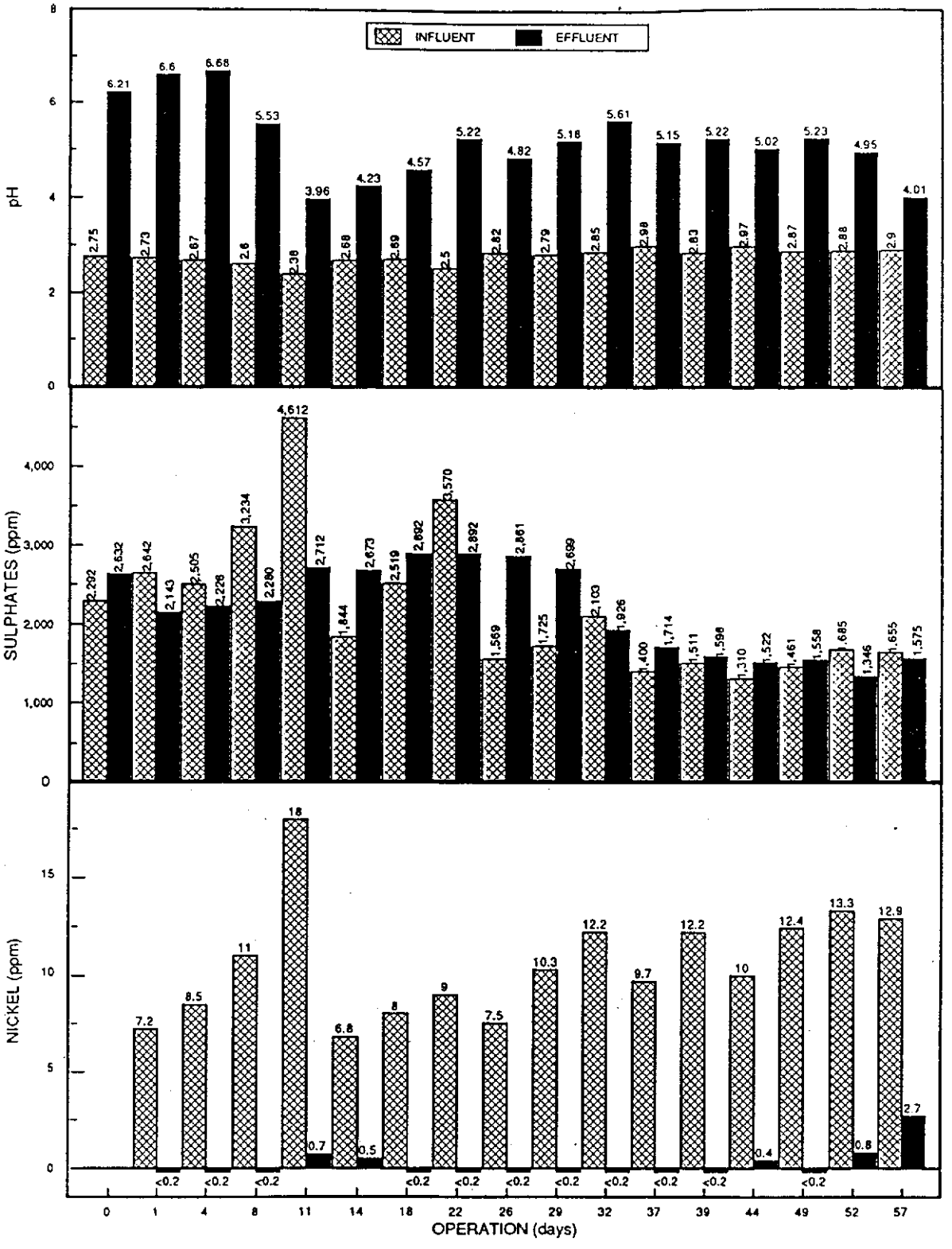


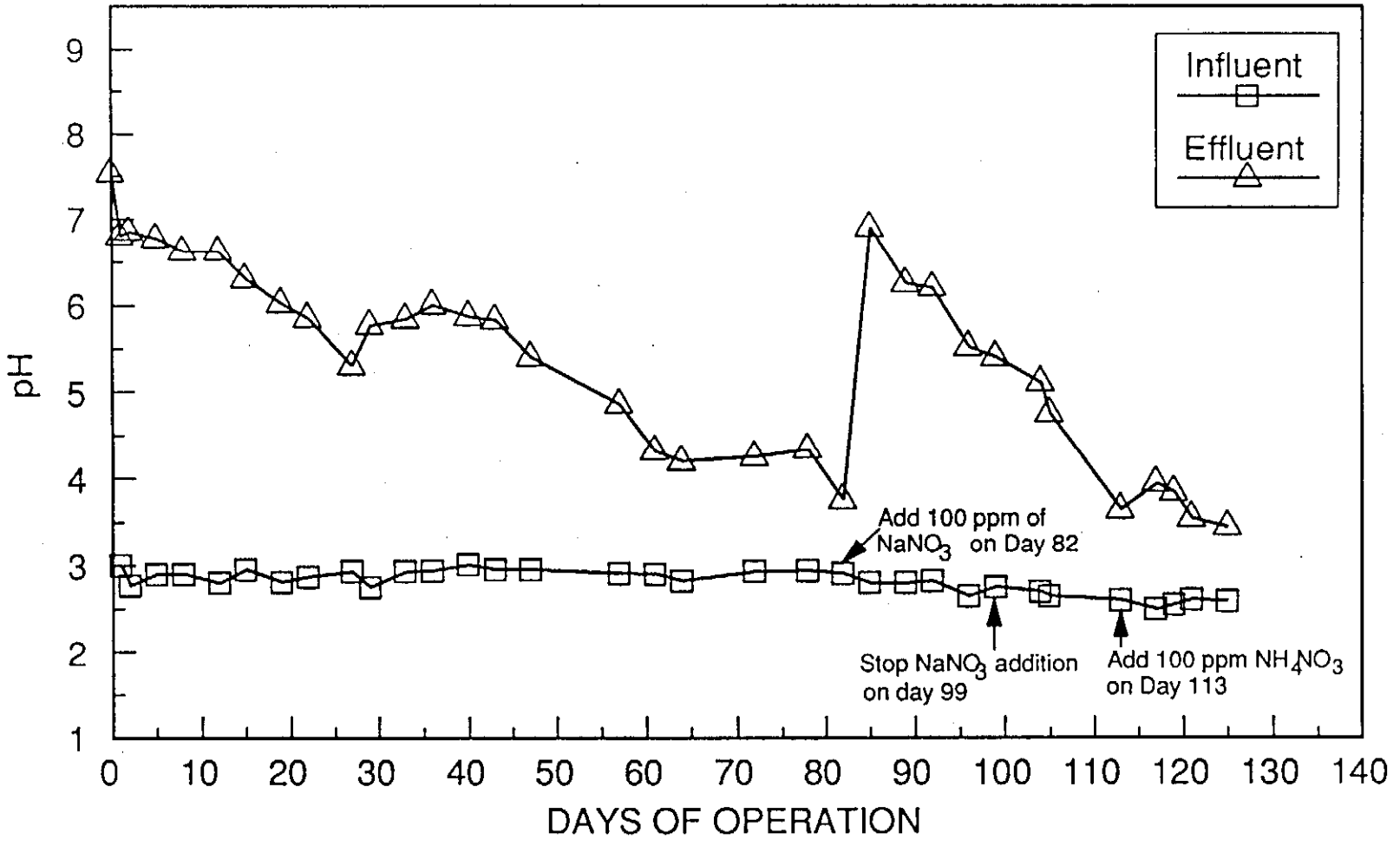
Figure 37: Flow Experiment: Makela Reactor #3: 100 mL/Day

sulphate levels. Makela flow experiment II: In a similar experiment, flow rates of 100 mL/day were again used, but the flow configuration was altered to better emulate field conditions.

The ARUM process continued for a total of 125 days in this experiment. After 82 days of operation, when pH levels decreased to below 4 (Figure 38) 100 mg/L of $NaNO_3$ were added to the influent. By day 85, three days later, pH increased to 6.9. It appears that $NaNO_3$ provided a necessary component or nutrient for alkalinity-generation. It may have stimulated denitrification. On day 113, pH again decreased to below 4. One hundred mg/L of NH_4NO_3 was added to the reactor to test other forms of nitrogen for stimulation of alkalinity-generation, but this addition was unsuccessful.

The ARUM process continued for 125 days. Ni concentrations in the effluent were initially reduced to non-detectable levels by day 29. Subsequently, however, detectable amounts of nickel reappeared with increased sulphates levels and acidity (Table 11).

Iron concentrations in the influent and effluent samples (Table 11) were lower than during the first 26 days of the experiment. A different batch of seepage water was then used which had higher concentrations. Initially, iron was effectively reduced in the reactor. However, towards the end of the experiment the appearance of ferric iron, accompanied by increases in nickel, sulphate, and acidity in the effluent suggests an incomplete reduction in the influent. Nitrate concentrations decreased in effluent samples suggesting



Note: Acidic seepage pumped into reactor at flow rate of 100 mL/day

Figure 38: Alkalinity Generation in Makela Reactor #2

that nitrate was effectively consumed or degraded in the reactor. Ammonium levels may have been reduced in the effluent but, overall, levels are near the detection limit and may therefore be an artifact (Table 11).

Microbiological profiles were performed on samples obtained from the flow system. Tables 12 and 13 are a summary of the results. The population sizes of the microbial groups responsible for alkalinity-generation did not appear to change from one sampling period to another. This suggests that the failure of the reactor (inability to maintain a pH > 4) was not due to the death or elimination of any of the microbial groups.

Makela flow experiment III: Further flow rate experiments at 100 mL/day were conducted in two reactors. Reactor #1 had previously been exposed to excessive flow rates of 250 mL/day and failed. Reactor #3 had experienced flow rates of 500 mL/day and 100 mL/day and failed (June 1990 report).

At the flow rate of 100 mL/day, the ARUM process continued for 27 and 21 days in Reactor #1 and #3, respectively (Figure 39). Initially the reactors were able to recover and generate sufficient alkalinity to neutralize acidic seepage to above pH 6, but they were unable to maintain pH above 4 under flow conditions. It is interesting to note that in two separate reactors, similar results were observed. There is insufficient information available to deduce whether failure of the reactor was due to loss of alkalinity-generating

	Days of Operation													
	1	8	15	22	29	36	43	57	64	72*	96**	105	113***	119
pH influent	3	2.9	2.95	2.87	2.75	2.94	2.95	2.91	2.82	2.93	2.65	2.65	2.60	2.55
pH effluent	6.8	6.62	6.3	5.85	5.77	6.0	5.83	4.86	4.20	4.25	5.52	4.76	3.65	3.85
SO_4^{2-} influent (ppm)	1403	1471	1318	1220	1452	1141	1000	1227	1095	1019	4534	2900	3664	6254
SO_4^{2-} effluent (ppm)	1685	1351	1258	1244	1213	1042	1136	1017	1061	978	3986	2340	3132	6761
Ni influent (ppm)	12	13.6	13	11.4	12.7	10.2	10.2	11.4	10.0	83.2	36.2	51.6	56.6	57.1
Ni effluent (ppm)	3.0	0.7	0.7	0.5	<0.1	<0.1	0.2	0.20	0.70	11.7	<0.2	14.3	2.81	15.4
Fe^{3+}/Fe^{2+} influent	35/0	7/0	7/0	5.3/0	5.3/0	5.3/0	<4/0	<4/0	<4/0	<4/0	17.5/35	35/44	14/88	140/123
Fe^{3+}/Fe^{2+} effluent	0/123	0/<4	0/<4.0	0/8.8	0/7	0/7	0/7	0/8.8	0/7	0/7	0/44	9/61	0/193	0/230
NO_3 influent (ppm)	-	-	-	-	-	-	-	-	-	-	64	11.0	16.7	87
NO_3 effluent (ppm)	-	-	-	-	-	-	-	-	-	-	4.2	0.9	1.05	2.5
NH_4^+ influent (ppm)	-	-	-	-	-	-	-	-	-	-	-	10.4	11.8	80
NH_4^+ effluent (ppm)	-	-	-	-	-	-	-	-	-	-	-	9.7	12.2	20
S^{2-} influent	-	-	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
S^{2-} effluent	-	-	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	0.20	0.10

Note: N.D. = not detected
*Add 100 ppm of $NaNO_3$ on Day 82
**Stop addition of $NaNO_3$ on Day 99
***Add 100 ppm NH_4NO_3

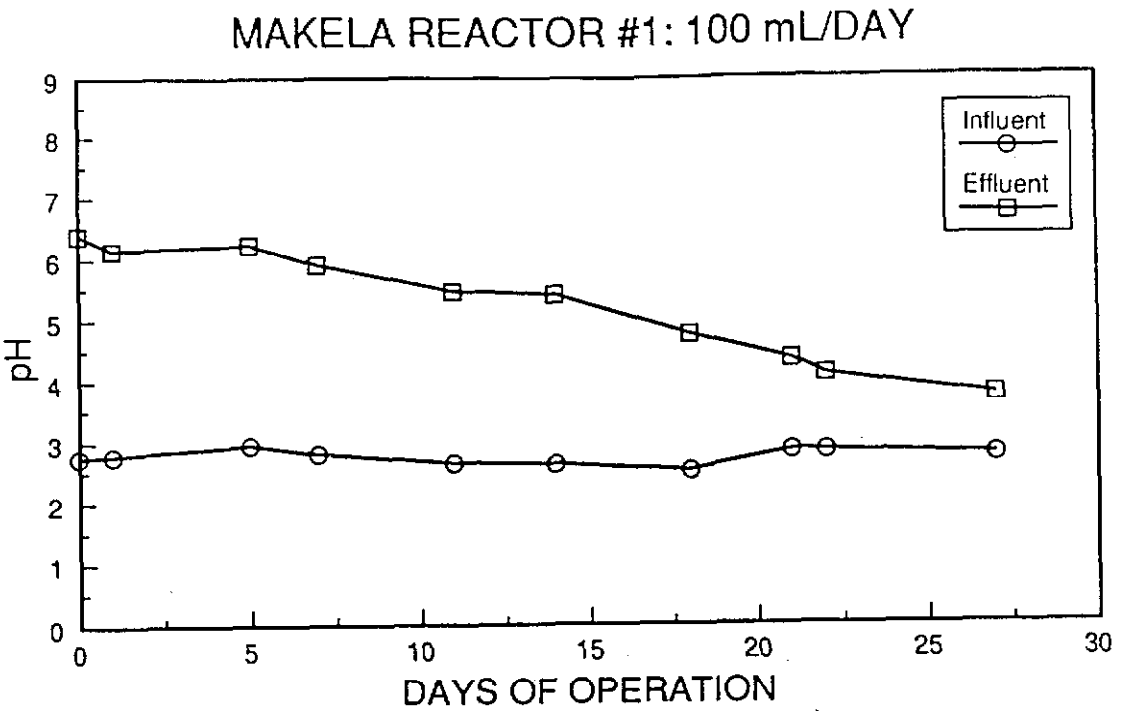
Table 11: Flow Experiment: Makela #2 Reactor: 100 mL/Day

	Iron Reducing Bacteria per mL	Ammonifiers per mL	Sulphate Reducing Bacteria per mL (Postgate B media)	Sulphate Reducing Bacteria per mL (Postgate F media)	Denitrifers per mL
Top Port	$\geq 10^5$	$\geq 10^5$	$\geq 10^4$	10^3	10^4
Middle Port	$\geq 10^5$	$\geq 10^5$	$\geq 10^4$	10^2	10^4
Bottom Port	$\geq 10^5$	$\geq 10^5$	$\geq 10^4$	10^2	10^3

Table 12: Microbiological Profile of Samples Obtained From Makela #2 Reactor on Day 99 Following Termination of $NaNO_3$ Treatment

	Iron Reducing Bacteria per mL	Ammonifiers per mL	Sulphate Reducing Bacteria per mL (Postgate B media)	Sulphate Reducing Bacteria per mL (Postgate F media)	Denitrifers per mL
Top Port	10	$\geq 10^4$	$\geq 10^4$	10^2	10^4
Middle Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^3	10^2
Bottom Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^2	10^3

Table 13: Microbiological Profile of Samples Obtained From Makela #2 Reactor on Day 113 Prior to NH_4NO_3 Addition



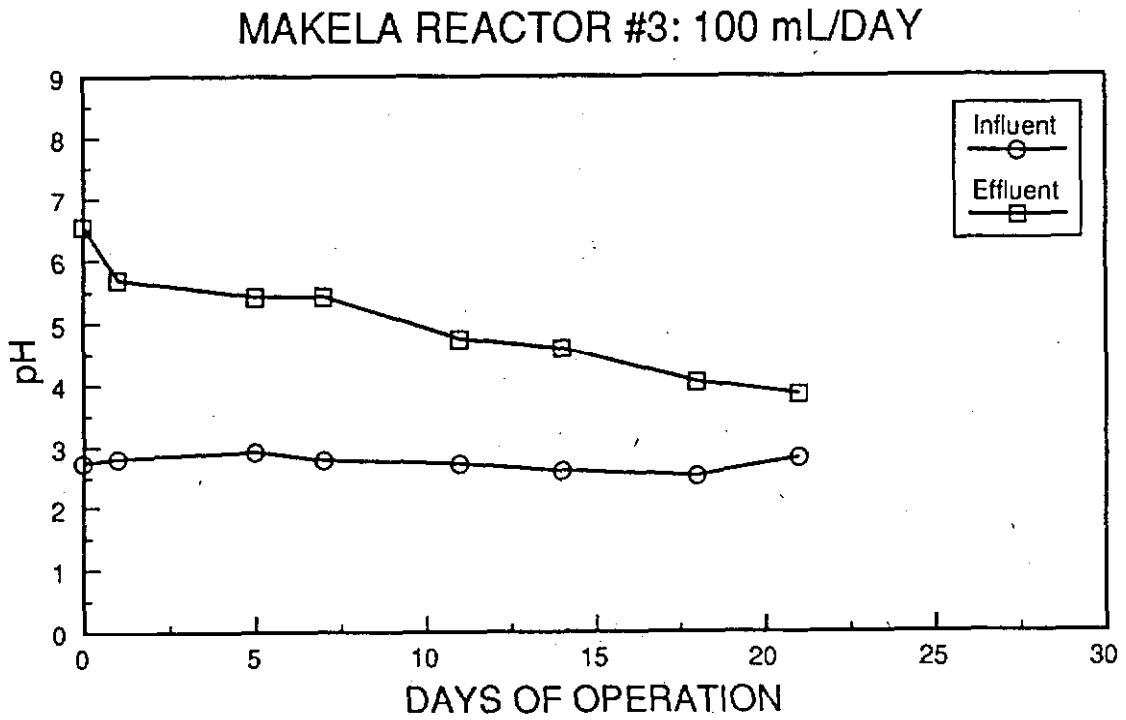


Figure 39: Flow Experiment: Makela Reactor #1 and #3

microbial groups, loss or exhaustion of an important nutrient necessary for biological reactions, or influent overloading.Denison Experiments: Flow-through ARUM Experiments were also conducted using Denison acidic seepage. All previous laboratory experiments for Denison had been performed in batches under static conditions.

Laboratory-scale water column reactors were established with Denison water. Successful initiation of microbial alkalinity-generation in Denison water was achieved (Table 14). Again, 100 mg/L of $NaNO_3$ was added to reactor #1 (Table 14). This time, however, the addition did not change the rate of alkalinity-generation in reactor #1.

A chemical analysis was performed on pre-flow samples obtained from reactors #1 and #3. Data are given in Tables 15 and 16. The analyses are similar, indicating that both contain the same type of water. A microbiological profile was also performed on samples obtained from the 2 reactors (Table 17). All microbial groups are present in the reactors, although some occur only in certain areas of the reactor. High concentrations of iron-reducing bacteria, ammonifiers and sulphate-reducing bacteria were present. While the denitrifier population was low, it was still present and would be capable of utilizing NO_3 as a nutrient source for growth. The concentrations of iron-reducing bacteria in samples from reactor #1 bottom port and reactor #3 middle port were very low.

	pH		
Days of Incubation	Reactor #1	Reactor #2	Reactor #3
0	2.70	2.70	2.70
14	3.85	4.48	3.93
	Added 100 ppm $NaNO_3$ to Middle Port	Added Nothing	Added Nothing
21	*4.75	*4.95	*4.81
26	*5.08	*5.16	*5.12
33	*5.77	-	*5.68
40	*5.55	-	*6.10

*Blackening observed in reactor indicating the presence of sulphate reducing bacteria

Table 14: Denison Reactor Experiments - pH Profiles

Sample	Total Soluble Carbohydrate (ppm)	Nitrate (ppm)	Sulphate (ppm)	Sulphide (ppm
Top Port	47	9.28	947	N.D.
Middle Port	48	7.55	921	<0.10
Bottom Port	30	12.91	941	0.95

N.D. = Not detected

Table 15: Chemical Profile of Samples Obtained From Denison Reactor #1 Prior to Flow

Sample	Total Soluble Carbohydrate (ppm)	Nitrate (ppm)	Sulphate (ppm)	Sulphide (ppm)
Top Port	53	13.4	915	<0.10
Middle Port	38	14.2	875	<0.10
Bottom Port	15	17.1	1095	0.92

Table 16: Chemical Profile of Samples Obtained From Denison Reactor #3 Prior to Flow

Sample	Iron Reducing Bacteria per mL	Ammonifier per mL	Sulphate Reducing Bacteria per mL (Postgate B media)	Sulphate Reducing Bacteria per mL (Postgate F Media)	Denitrifiers per mL
Denison #1 Top Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^2	<1
Denison #1 Middle Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^2	10
Denison #1 Bottom Port	<1	$\geq 10^4$	$\geq 10^4$	10^3	10
Denison #3 Top Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^2	<1
Denison #3 Middle Port	<1	$\geq 10^4$	$\geq 10^4$	10	10
Denison #3 Bottom Port	$\geq 10^4$	$\geq 10^4$	$\geq 10^4$	10^3	<1

Table 17: Microbiological Profile of Samples Obtained From Denison Reactors 1 and 3 Prior to Flow

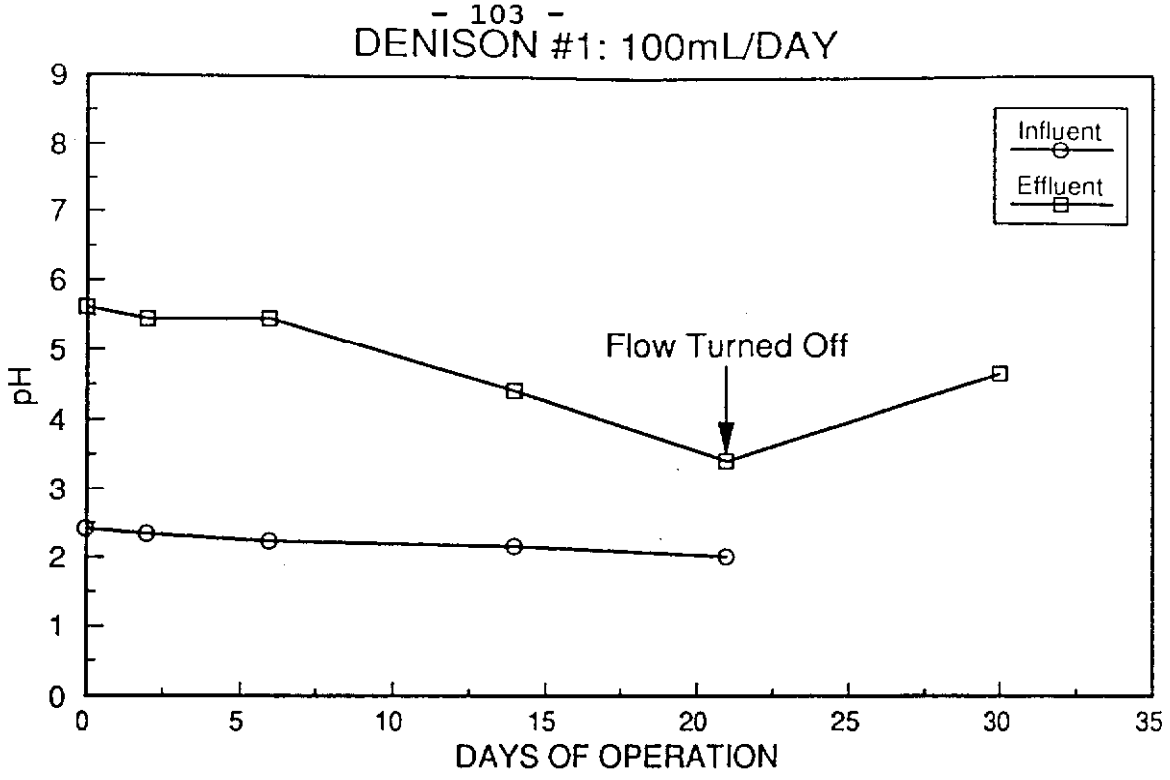
Denison flow experiment I: Flow experiments were started when the reactor had reached pH 5. From the information in Figure 36 it was clear that most of the alkalinity would be required to raise the pH to 4.5. It could be that the Denison reactors have a lower reservoir of accumulated neutralizing capacity, compared to Makela reactors, at pH 5. The ARUM process continued for approximately 21 days (Figure 40).

Following a recovery period of 9 days, the reactor effluent increased to pH 4.5 suggesting that the alkalinity-generating process was not irreversibly inhibited, but could continue.

In summary, the reactors were unable to maintain the ARUM process during flow operation after the replacement of approximately one reactor volume of 1.5 L. In addition, pretreatment of the reactor with low nitrate levels did not prevent failure of the reactor.

Denison flow experiment II: The Denison water column reactor #3 had previously been exposed to flow rates of 100 mL/day for 21 days. It was tested to see if, following a recovery period of 1.5 months, a flow rate of 100 mL/day could be resumed. The ARUM process continued for 14 days (Figure 41) approximately equal to the fluid retention time of the reactor (15 days).

A microbiological profile was performed on samples taken before the initiation of the flow experiment and following the failure of the reactor (Table 18). The population sizes of



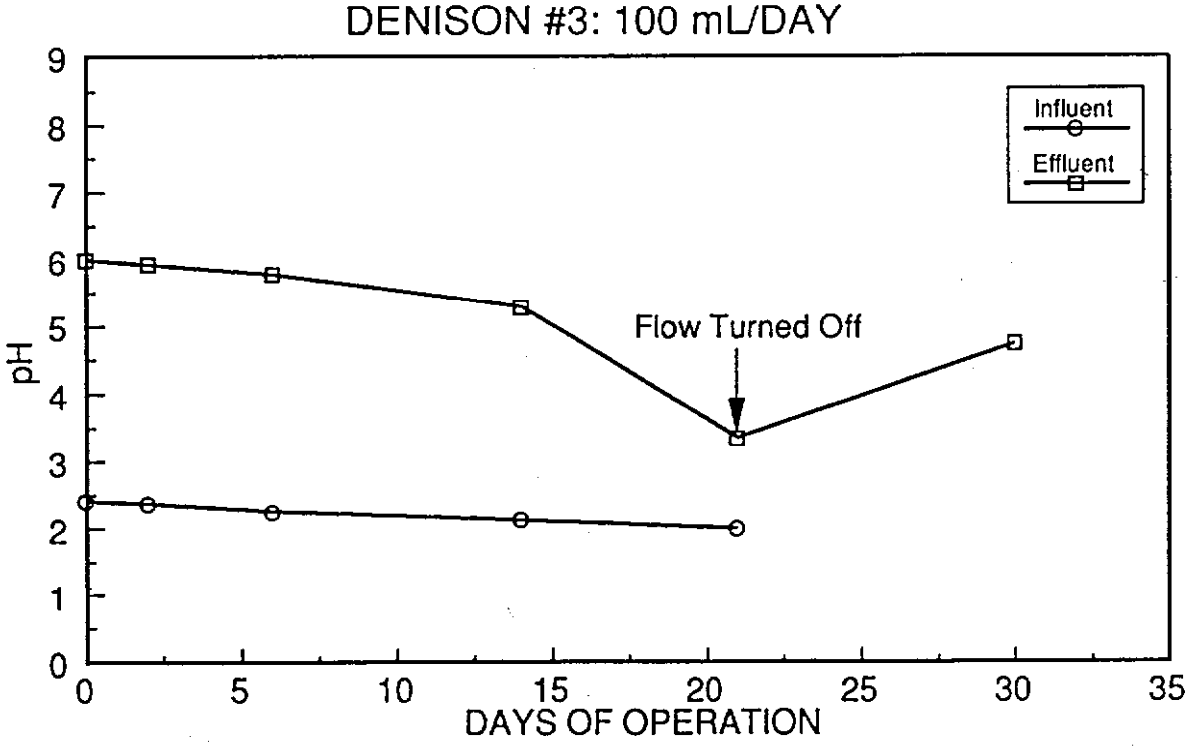


Figure 40: Flow Experiment: denison Reactor # 1 and #3

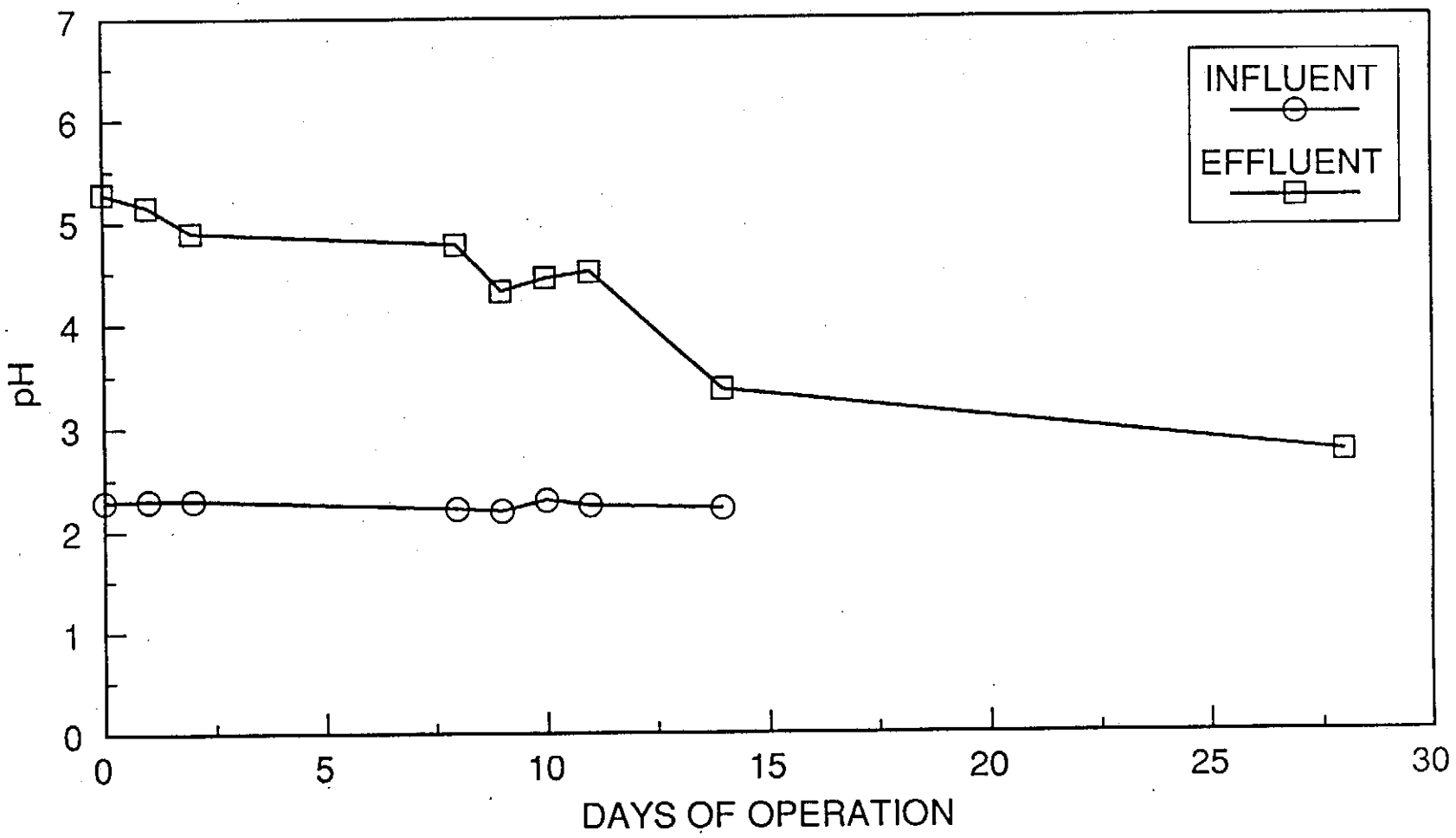


Figure 41: Flow Experiment: Denison Reactor #3: 100 mL/Day

microbial groups remained constant except for the volatile fatty acid (VFA) producers whose numbers had decreased.A number of explanations are possible. The low numbers of VFA producers may be due to the toxic effects of the acidic seepage or the flow-through conditions may have washed out large numbers of bacteria. On the other hand it may be possible, that carbohydrate levels in the reactor prior to flow and following failure were limiting (Table 19). Soluble carbohydrates are nutrient sources for these bacteria and may therefore be limiting VFA producer numbers. Volatile fatty acids were, however, detected in low concentration in the bottom of the reactor (Table 20).

Sulphate concentrations in Denison #3 reactor prior to the initiation of flow and following the initial failure of the reactor are presented in Table 21. A comparison of influent and effluent sulphate levels, suggests that sulphate reduction may have occurred, but only if an even distribution of sulphate in the reactor is assumed.

Table 22 illustrates the metabolic activity in the reactor as measured by CO_2 production. Three days following flushing of the headspace of the reactor, CO_2 levels were measured. It should be noted that although the reactor had failed (inability to maintain pH >4) the reactor was still able to generate CO_2, indicating the presence of biological activity.

Sample	Iron Reducing Bacteria Per mL	Ammonifiers Per mL	Sulphate Reducing Bacteria Per mL (Postgate B Media)	Sulphate Reducing Bacteria Per mL (Postgate F Media)	Denitrifiers Per mL	Volatile Fatty Acid Producers Per mL	ATP (ng/mL)
Bottom Port (before initiation of flow)	10^3	10^2	10^4	10^2	<1	$\geq 10^5$	2.1
Bottom Port (at failure of reactor)*	10	10^2	10^4	10^3	<1	<1	0.40

*Flow to reactor was turned off on failure (unable to maintain pH >4.0)

Table 18: Microbiological Profile of Samples Obtained From Denison Reactor #3

	Total Soluble Carbohydrate (ppm)		
Sample	Before Initiation Of Flow	At Failure Of Reactor*	10 Days After Failure Of Reactor
Top Port	N.A.	N.A.	N.A.
Middle Port	<10	<10	<10
Bottom Port	<10	<10	<10

Table 19: Total Soluble Carbohydrate Analyses in Denison Reactor #3

	Total Volatile Fatty Acids (ppm)		
Sample	Before Initiation Of Flow	At Failure of Reactor*	10 Days After Failure of Reactor*
Top Port	N.A.	N.A.	N.A.
Middle Port	N.A.	N.A.	N.A.
Bottom Port	270	<200	<200

Note: N.A. = not analyzed.
*Flow to Reactor was turned off on failure (unable to maintain pH >4.0)

Table 20: Total Volatile Fatty Acids in Denison Reactor #3

Sample	Total Sulphates (ppm)		
	Before Initiation Of Flow	At Failure Of Reactor*	10 Days After Failure of Reactor*
Top Port	1282	2227	1828
Middle Port	1225	2545	1916
Bottom Port	N.A.	N.A.	2035
Influent	1919	3114	N.A.

Table 21: Sulphate Analyses in Denison Reactor #3

	CO_2 (ppm)
10 days after reactor failure*	1900
Following flushing of reactor headspace	380
3 days following flush**	1720

*Flow to reactor was turned off on failure (unable to maintain pH >4.0)
**Reactor pH at top port = 2.8 (ie. still <4.0)

Table 22: Metabolic Activity in Denison Reactor #3 Measured CO_2 Production

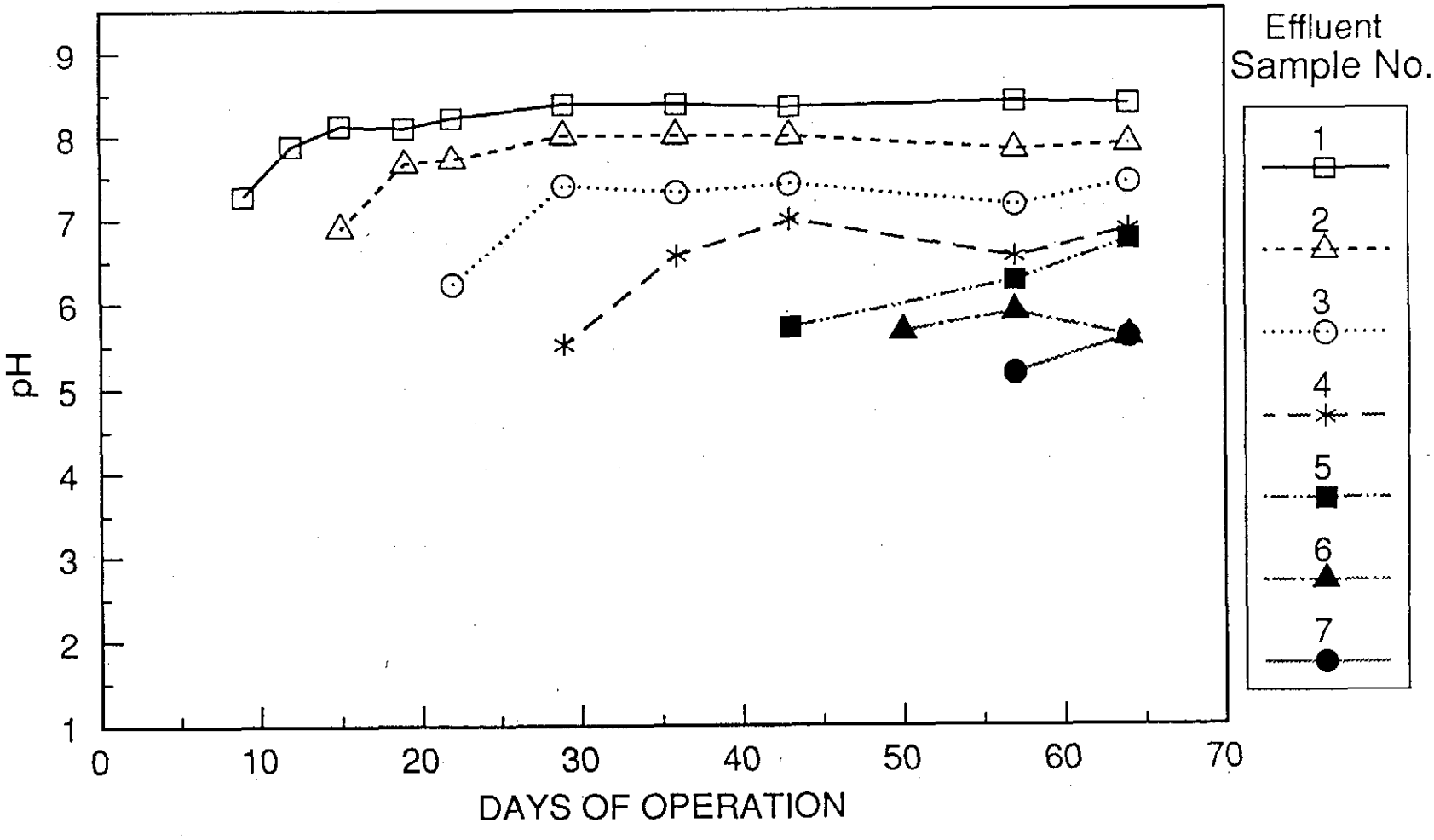
4.3 Stability Of The ARUM Effluent

It is essential that the effluent produced from the flow reactors and the batch treatment be stable, i.e. that the effluents do not re-acidify. The characteristics of the effluents from the flow reactors and batch treatments are discussed below.

The effluents from Makela flow experiments II and III were observed after varying time periods. After 57 days, the pH of the effluent from experiment II remained stable and in fact it increased slightly (Figure 42).

The effluent from experiment III removed from reactors #1 and #3 on day 2 did not re-acidify. The pH was maintained for the following 25 days (Tables 23 and 24). In contrast, effluent taken at a later date did re-acidify. It appears, therefore, that an effluent with a pH of less then 4.5 is not stable. This confirms previous findings that stable ARUM effluent has to have a pH of 5 or higher.

Amendments and substrate placed in cages in the field were collected and placed in glass jars in the lab. After approximately five months, water samples were taken from the jars, divided into two subsamples and placed in 250 mL Ehrlenmeyers flasks. One set of Ehrlenmeyers was incubated at room temperature, while the other set was incubated in a refrigerator at 8°C.



NOTE: First data point indicates day removed from effluent reservoir.

Figure 42: Stability of Effluent pH: Makela Reactor #2

	Effluent Sample No.		
Days of Operation	1	2	3
2	*6.40	-	-
8	6.58	-	-
15	6.61	*5.45	-
22	6.55	5.75	*4.30
27	6.60	5.80	3.45

Table 23: Stability of Effluent pH: Makela Reactor #1

	Effluent Sample No.		
Days of Operation	1	2	3
2	*6.22	-	-
8	6.00	-	-
15	-	*3.00	-
22	-	2.72	*2.81
27	6.00	2.68	2.67

Note: *First data point indicates day removed from effluent reservoir

Table 24: Stability of Effluent pH: Makela Reactor #3

The concentrations of ferrous and ferric iron were approximated with colorimetric methods which, although not reliable, give some indication of the relative concentrations of the two iron species. The pH was also monitored in the samples. Those results, together with the description of the types of precipitates formed in the flasks (presence of flake precipitates, flocculants, "plating", or precipitation of compounds onto the glass wall, solution clarity and colour) were presented in the l990 report (Kalin 1990).

Solution pH was measured regularly for 64 days. Ferrous and ferric concentrations were determined 0, 4, 8, 12, and 64 days after sampling, as were qualitative observations on the precipitate formation. Results are presented in Figure 43 for 3 types of AMD (coal, uranium, base metal) at 4 sites, under static conditions. Relative concentrations will change if microbial alkalinity-generation is reversed.

Overall, pH trends could not be discerned according to amendment types or placement techniques applied at the 4 original sites. More importantly, pH changes appeared to be related to the specific AMD tested, e.g., pH values increased in Makela water.

Both Straw Pond (Denison) and PBAC (Levack tailings, Pre-Bog Acid Creek - original organic amendment test site) waters were characterised by high concentrations of ferric and ferrous iron (100-500 mg/L), while the solutions of Makela and Devco sampled from the jars contained low concentrations of both iron species (5 - 90 mg/L).

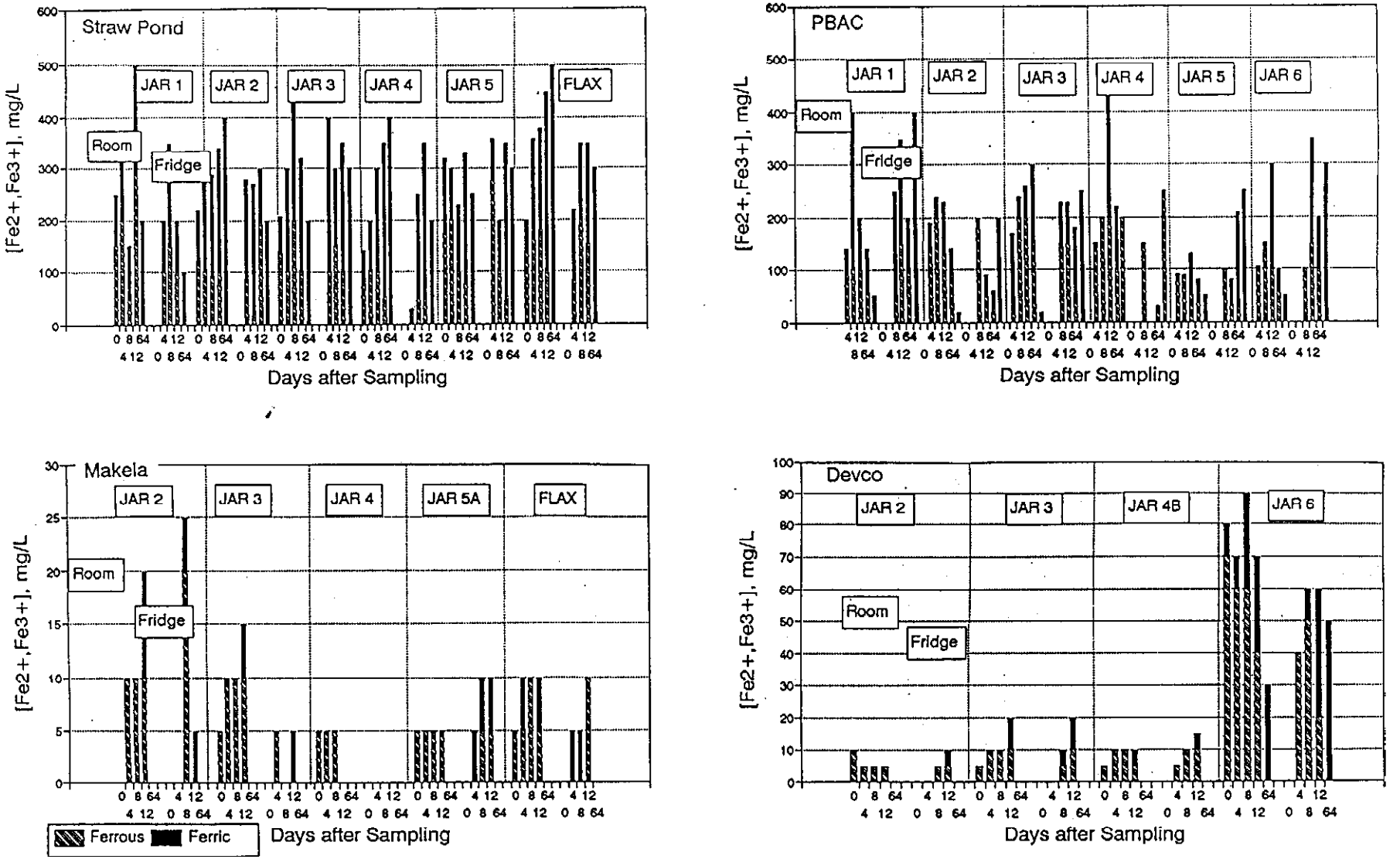


Figure 43: Ferric, Ferrous Ratios of Batch Effluent

In the case of Straw Pond (Denison) solutions, there was no sign of significant alkalinity-generation prior to sampling. The pH remained low in the weeks following sampling. In the case of PBAC, the pH values started out at pH 5.0, but subsequently decreased within days of sampling, and remained low.

Makela solution pH values were neutral at the time of sampling, remained steady in the refrigerator, but increased with incubation at room temperature. The pH of only one of four Devco treatments increased after sampling at room and refrigerator temperatures (Jar 3B, Straw). In the remaining three treatments, pH decreased to 2.5-3.9. For ease of reference the pH data and qualitative descriptions are reproduced in Appendix 1.

The concentrations of both iron species for Straw Pond (Denison) water were typically higher when water samples were incubated at room temperature. Roughly half of the iron in solution was in the ferrous form after the first week of incubation, but by the end of the period of observation, iron in solution was exclusively in the ferric form. There was little evidence of iron precipitation; total iron concentrations remained above 100 mg/L by the end of the observation period, and were generally at similar levels over the period of observation.

The first week after sampling the PBAC solution, there was more ferrous than ferric iron. However, by the end of the observation period, no ferrous iron was detected in five of the six treatments sampled. At the same time, concentrations of ferric iron in solution decreased, suggesting precipitation of iron.

The sample taken from Jar 4 was the exception to the above trend. By the end of the observation period, all iron in solution was in the ferrous form, suggesting that the solution had neither re-oxidized nor had precipitation occurred. At the end of the incubation period, the room temperature and refrigerator samples of Jar 4 varied by plating colour; in the case of the refrigerator sample, fungal colonization was observed.

As stated above, the total concentration of iron was relatively low in Makela solutions. No differences between treatments could be discerned, although this may be the result of the ferric/ferrous test, which measures concentration in 5 mg/L steps. Overall, qualitative observations indicate that the Makela solutions maintained pH values higher than 5 and readily supported algal colonization at room temperature in the laboratory.

The long-term conversion of ferrous iron to ferric iron, observed in Straw Pond and PBAC solutions, was also observed in Devco solutions. This was particularly true for the sample from Jar 6, where iron concentrations were high. By day 64, dissolved iron from the room temperature treatment of the Jar 6 sample was exclusively in the form of ferric iron. However, precipitation of iron was not observed in Devco samples, where total iron levels remained relatively constant over the period of observation.

These observations, although extremely qualitative, concur with the flow-through reactor results, in that an effluent pH of 5 or higher is required for the assurance that iron has been removed from solution, and will not re-acidify.

4.4 Limiting Factors of Alkalinity-Generation

From the test results of microbial alkalinity-generation in the batch field and laboratory work, it is evident that time is required for microbial ecosystems to generate alkalinity. This time requirement may be related to the availability of organic carbon, which may be limited by decomposition rates. On the other hand, it may be possible that conditions must reach the appropriate redox level. As the Denison seepage clearly presents the greatest difficulties for the establishment of the ARUM process, reactors with Denison seepage were used to investigate the limiting factors of microbial ecosystems.

4.4.1 Testing additives for alkalinity-generation

Earlier ARUM experiments demonstrated that addition of iron filings produced an increased pH. Further tests were carried out with different forms of iron. Successful alkalinity-generation was achieved by oxidized and elemental forms of iron. After a 3 week incubation period, vials containing iron filings and rusted iron filings were blackened. One week later, the vials containing rusted iron finishing nails were blackened. This suggested that both forms produced conditions which brought about blackening of the substrate. Although not conclusive, blackening is assumed to be due to sulphate reducers.

Other additives which might affect alkalinity-generation were also tested. Treatments tested were flax alone, flax + iron filings, flax + $Ca(NO_3)_2$, flax + $NaNO_3$, and flax + Na_2SO_3 (Table 25). At the end of the experiment all treatment except for flax alone were capable of stimulating alkalinity-generation.

$Ca(NO_3)_2$ and $NaNO_3$ were added as a nutrient in order to stimulate the denitrification process. Na_2SO_3 was added as a reducing agent. Although alkalinity had been generated in the vial containing $NaNO_3$ by day 28, there was no evidence for sulphate-reducing bacteria even by day 74. The addition of $Ca(NO_3)_2$ appeared to elicit a stimulatory response resulting in alkalinity-generation and growth of sulphate-reducing bacteria (blackened vial) was observed by day 74. The vial containing Na_2SO_3 was blackened by day 42 of incubation, suggesting the presence of SRB. However, it is possible that some or all of the sulphides could have been produced by micro-organisms which reduce sulfite.

The theoretical chemical contribution of each treatment to alkalinity was summarized in Table 26 and compared to the amount of alkalinity-production observed in vials according to the titration curve shown in Figure 36.

Two different initial pH values were used to determine the milliequivalents (meq) of alkalinity produced. The pH of the acidic seepage water used in the experiment was 2.45. However, addition of flax to the vial raised the pH to 3.08. Therefore, it was

important to determine the meq of alkalinity produced to raise the pH from both starting pH values.

The addition of $Ca(NO_3)_2$ contributed 2 meq of alkalinity, that is 8 to 20% of total alkalinity (based on meq produced to raise pH from 2.45 and 3.08, respectively). Chemical addition of $NaNO_3$ produced 5 meq of alkalinity representing 23% to 71% of total alkalinity generated. Na_2SO_3 addition contributed 8 meq of alkalinity, that is, 30% to 73% of total alkalinity produced.

These results suggest that alkalinity-generation is not due solely to the additives. Microbial processes are contributing to alkalinity-generation. These results may have additional significance, since until now, iron had been the only successful supplement for the initiation of alkalinity-generation (Kalin 1990).

The pH increases due to flax addition were investigated further. Flax was ground (< 20 mesh) and added sequentially to 200 mL of three types of AMD. In Figure 44 the results of the additions are given. As more and more milled flax was added to the seepage water (up to 10 g), the pH increased slightly, inversely proportional to the total acidity. The AMD with the lowest acidity produced the greatest pH increase and the most impressive decrease in pE. Organic substances, it appears, release alkalinity.

For two months after the milled flax addition, pH and pE measurements were taken. Some alkalinity-generation was noted (Figure 45). This does suggest that there is likely

a benefit in finding those components which are required to initiate microbial systems, ie. provide the best conditions.

The contribution of iron to the initiation of the microbial process was examined. Amendment/water vials were sterilized by a Tyndalization method (Brock et al. 1984). Incubation of vials at 80° C for 10 minutes was repeated 3 times over several days allowing spores to germinate. The Tyndalization method was chosen since sterilization by autoclaving may have resulted in chemical alteration or decomposition of the amendment.

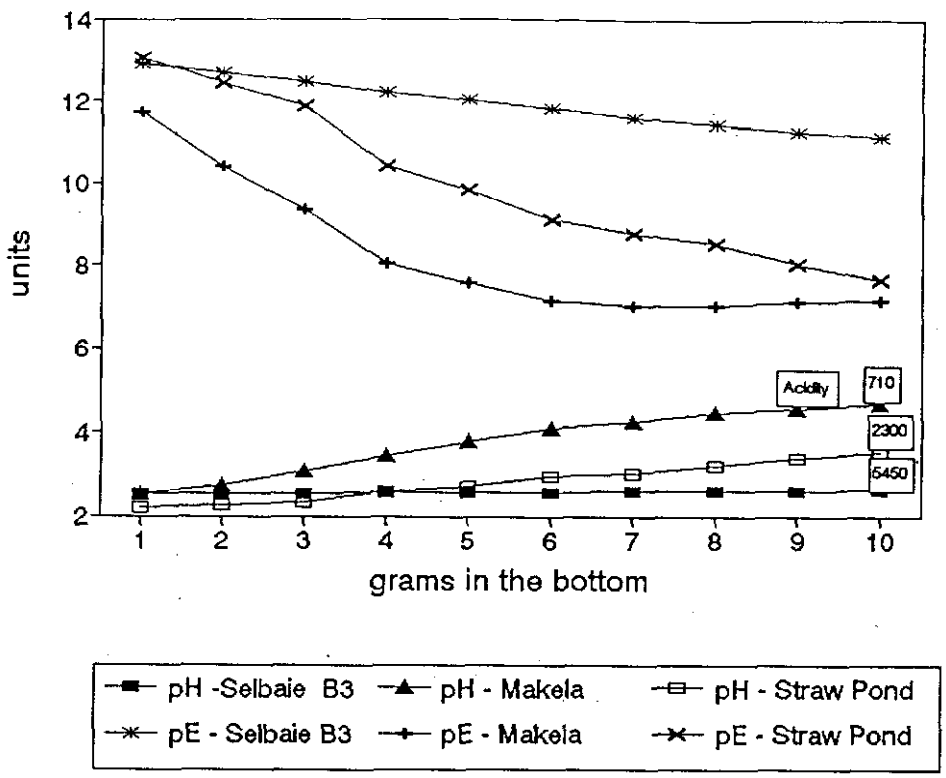


Figure 44: Milled Flax additions to 200 ml AMD

Amendment		pH after 28 days	pH after 42 days	pH after 74 days
1	Flax	3.08	2.97	3.01
2	Flax and Iron Filings	*6.52	*6.65	-
3	Flax and Iron Filings	*6.42	*6.45	-
4	Flax and 400 ppm $NaNO_3$	3.27	3.41	3.76
5	Flax and 200 ppm $Ca(NO_3)_2$	3.81	4.05	*6.75
6	Flax and 500 ppm Na_2SO_3	4.23	*5.45	*6.52

*Blackening of vial observed indicating the presence of sulphate reducing bacteria

Note: pH of water added to vial = 2.45

Table 25: Results of Screening Tests to Develop Alkalinity Generation in Denison Water

Treatment	pH After 28 Days	Meq of Alkalinity Produced to Raise pH from		Theoretical Alkalinity (meq) Contributed by Added Cations*
		2.45	3.08	
200 ppm $Ca(NO_3)_2$	3.81	25	10	2
400 ppm $NaNO_3$	3.27	22	7	5
500 ppm Na_2SO_3	4.23	27	11	8

*This is the alkalinity which would be produced if the anion of the treatment was consumed or lost by non-alkalinity generating abiotic processes (eg. volatization)

Table 26: Total vs. Theoretical Chemical Contribution to Alkalinity From ARUM Treatments With Denison Water

The results of the experiment are summarized in Table 27. Following the final heat treatment, the pH of the vial containing iron did not change, demonstrating that iron does not contribute to alkalinity. Similarly, flax alone did not contribute to the initiation of alkalinity. However, the pH of the vial containing flax and iron filings, after the third heat shock, did change. Although the pH did increase, it was still less than 3. It is unlikely that the gravel in the vials contributed to this rise in pH as all vials contained material from the same gravel batch.

Sterilization with flax and iron may have eliminated or enriched an essential microbial component, and hence an experiment was carried out to identify which of the different microbiological groups present in the ARUM system are capable of independently generating alkalinity. Vials containing gravel and acidic seepage were inoculated with pure cultures of sulphate-reducing bacteria, iron-reducing bacteria and ammonifier bacteria (Table 28).

Prior to inoculation, the vials were sterilized by Tyndalization. Before the first heat shock, an ATP assay was conducted as a measure of total microbial activity on the control vials containing iron filings and sodium lactate. It was found that they contained 2.1 ng and 2.6 ng ATP/mL. Following the third heat shock (before addition of the bacteria) the ATP level was found to be 0.41 and 0.46 ng ATP/mL for control vials 1 and 2. Following a 3 week incubation period, ATP levels of control vials 1 and 2 decreased to 0.27 and 0.24

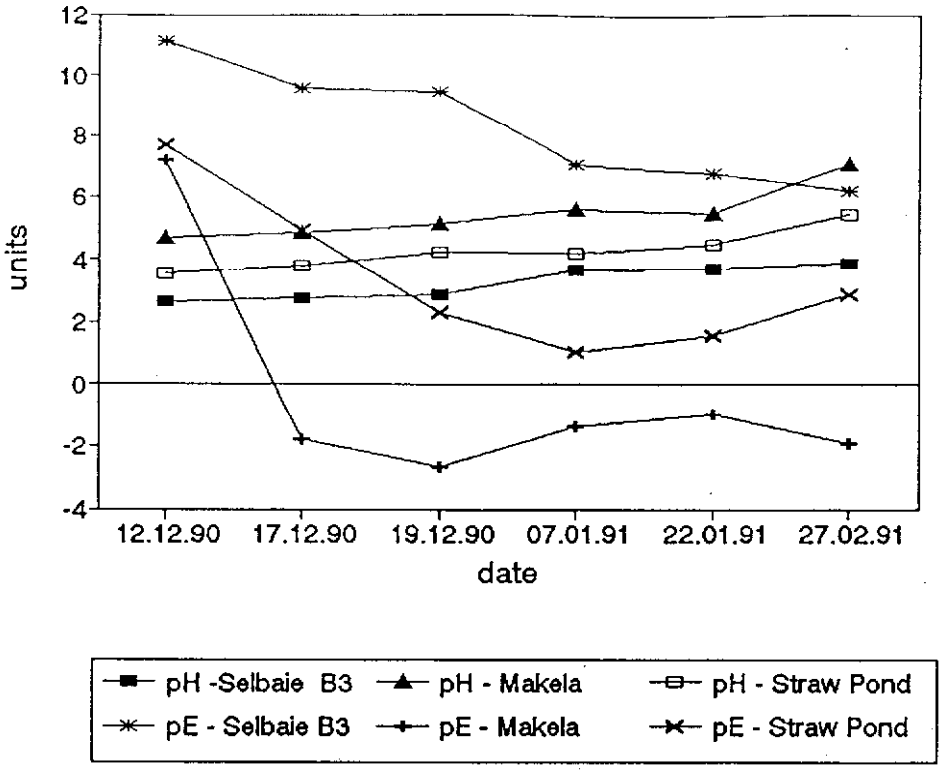


Figure 45: Development of Alkalinity Generation with Milled Flax

		pH		
No.	Amendment	Before Heat Shock*	Following First Heat Shock*	Following Third Heat Shock*
1	Flax and iron filings	2.23	2.46	2.81
2	Flax	2.22	2.23	2.35
3	Iron filings	2.25	2.15	2.24

Note: All vials contained gravel and Denison acidic seepage water.
* Heat shock was 10 minutes at 80° C. Intervals between heat shock was 2 days.

Table 27: Treatment of Denison Acidic Seepage: Mechanisms of Alkalinity Generation, Experimental Controls

Amendment	Vial #	ATP (ng/mL) Before Addition Of Bacteria	pH Before Addition of Bacteria	pH 3 Weeks After Addition Of Bacteria	ATP (ng/mL) 3 Weeks After Addition Of Bacteria
Iron filings and sodium lactate	1	0.41	<3.0	3.47	0.27
(Control)	2	0.46	<3.0	3.60	0.24
Iron filings, sodium lactate and 1 mL of sulphate reducing bacterial culture	3	0.33	<3.0	**5.91	-
	4	0.45	<3.0	*5.64	-
Iron filings, sodium lactate and 1 mL of iron reducing bacterial culture	5	0.41	<3.0	3.67	-
	6	0.33	<3.0	4.78	-
Iron filings	7	0.25	<3.0	4.10	0.68
(Control)	8	0.18	<3.0	4.65	3.80
Iron filings and 1 mL of ammonifier bacterial culture	9	0.16	<3.0	*5.30	-
	10	0.41	<3.0	4.05	-

* Vials were blackened indicating the presence of sulphate reducing bacteria
** Vial was blackened 6 days after addition of bacteria

Notes:

1. All vials contained gravel, flax and Denison acidic seepage water.

2. Test for the presence of iron reducing bacteria in vials #5 and #6 to be confirmed.

3. Tests for the presence of ammonifier bacteria in vial #10 to be confirmed.

Table 28: Determination of Microbiological Groups Capable of Independently Initiating Alkalinity

respectively, suggesting a lack of microbiological activity. It was suspected that the low levels of ATP in the vials at the beginning of the experiment was due to the presence of residual ATP from stressed cells. The fact that the ATP levels decreased following a 3 week period was consistent with the suspicion of the presence of residual ATP. Although ATP levels remained low, an increase in pH was observed in the control vials. A possible explanation may be the abiotic hydrolysis of sodium lactate.

Blackening of the vial containing sulphate-reducing bacteria was observed on day 6. Rapid blackening suggests, but does not prove, that sulphate-reducing bacteria are capable of initiating alkalinity-generation. There is uncertainty in this observation since there was evidence that the amendment was not completely sterilized (vial #9 following 3 week incubation period).

The pH of vial #5 which contained an iron-reducing bacterial culture was 3.67 after a 3 week incubation period. This value was similar to that of control values (pH 3.47 and pH 3.60). It appears that the bacterial culture was inactive in this vial. However, vigorous activity (bubbling) was observed in a duplicate vial (#6). Tests for the presence of iron-reducing bacteria in vials #5 and #6 are to be carried out at a later date.

An ATP assay was also conducted on control vials #7 and #8, containing iron filings alone. Before the beginning of the experiment, it was found that they contained 0.25 and 0.18 ng ATP per mL, respectively (comparable to control vials #1 and #2). However, following a 3 week period, ATP levels increased to 0.68 ng and 3.80 ng per mL

respectively, and pH increased to 4.65. This suggests that the sterilization technique was ineffective and failed to prevent the growth of a population capable of producing alkalinity.

Inconsistent results were also observed in vials inoculated with ammonifier cultures. Evidence of blackening was observed in one vial indicating the presence of sulphate-reducing bacteria. This again demonstrated that the sterilization technique that was used was ineffective in preventing growth of alkalinity-generating micro-organisms.

The pH of vial #10 containing a culture of ammonifiers was 4.05 after a 3 week incubation period. This pH value was similar to that of the control (pH 4.10). It appears that the bacterial culture was inactive in this environment. Tests for the presence of ammonifier bacteria in vial #10 are to be carried out at a later date.

In summary, it is unclear from these results which microbiological groups are capable of independently initiating alkalinity. Further experiments are required to define this phenomenon.

Although the attempt to identify an independent microbial group in the alkalinity-generating process was inconclusive, it is clear, that metabolic activity is present in the reactors. It can be detected through the measurement of CO_2 and methane.Denison and Makela water column reactors were analyzed for the accumulation of CO_2 and methane gas. The reactor headspace was then flushed with air. Following a 3 day incubation period, CO_2 levels were determined. CO_2 regeneration was used as a rapid test for

Reactor	Profile Of Reactor Treatment	Total Volume of Acidic Seepage Treated (L)	Accumulated Methane (ppm)	Accumulated CO_2 (ppm)	CO_2 (ppm) Following Flushing Of Reactor Headspace	CO_2 (ppm) 3 Days Following Flush
Makela #1	(i) Static for 2 months (ii) Acidic seepage pumped into reactor at rate of 250 mL/day for 23 days (iii) Static for 6 months (iv) Acidic seepage at rate of 100 mL/day for 27 days (v) Static for 2 months	10.9	0	3220	340	600
Makela #2	(i) Static for 4 months (ii) Acidic seepage pumped into reactor at rate of 100 mL/day for 125 days (iii) Static for 3.5 months	14.0	7	1680	400	1300
Makela #3	(i) Acidic seepage pumped into reactor at rate of 500 mL/day for 5 days (ii) Static for 1.5 months (iii) Acidic seepage at rate of 100 mL/day for 57 days (iv) Static for 5 months (v) Acidic seepage at rate of 100 mL/day for 21 days (vi) Static for 2 months	9.9	15	1100	340	760
Denison #1	(i) Static for 1 month (ii) Acidic seepage pumped into reactor at a rate of 100 mL/day for 21 days (iii) Static for 3 months	3.6	28	1140	400	800
Denison #2	(i) Static for 5 months	1.5	4300	5500	340	3025
Denison #3	(i) Static for 1.0 month (ii) Acidic seepage pumped into reactor at rate of 100 mL/day for 21 days (iii) Static for 1.5 months (iv) Acidic seepage at rate of 100 mL/day for 14 days (v) Static for 1 month	7.1	7	1900	380	1720

Table 29: Metabolic Activity in ARUM Water Column Reactors by Carbon Dioxide and Methane

biological activity in the reactor. Methane production is a measure of the activity of methanogenic bacteria. The results are summarized in Table 29 which shows that all ARUM water column reactors were able to regenerate CO_2, following flushing.

The most active reactor, in terms of both methane accumulation and CO_2 production and regeneration, was Denison reactor #2 which was kept under static conditions for a period of 5 months .

4.4.2 Organic matter decomposition and organic carbon supply

Benner et al. (1989) proposed that carbon from algae forms a major detrital component in aquatic systems and could be used as a nutrient source. Furthermore, Schoenberg et al. (1990) have studied the effects of acid stress on the decomposition of algae and found that algal decomposition was less sensitive to low pH than was decomposition of lignocellulose. In the Test Cell System, shortly after the placement of the amendment curtains, an extensive algal bloom was noted. It was associated with increased pH values in the cells. Therefore, periphytic algae, grown in the laboratory were used to test their capability to initiate alkalinity-generation.

Successful initiation of alkalinity-utilizing algae was achieved using Buchans acid seepage water (Table 30). The algal biomass stimulated a rapid increase in numbers of sulphate-

reducing bacteria within a two week period (blackening of the vial). The vial containing flax alone was also successful in initiating alkalinity within 2 weeks, but there was no evidence of blackening (indicating the presence of sulphate-reducing bacteria) until day 21 suggesting that other bacteria are involved in alkalinity-generation in this system.

Amendment		pH at beginning of test	pH after 14 days	pH after 21 days
1	Flax	3.50	5.13	*6.22
2	Algae	3.50	*6.52	*6.93

*Blackening of vial indicating the presence of sulphate reducing bacteria

Table 30: Preliminary Evaluation of Algae as an Amendment for The ARUM Process

Cellulose is the prime source of carbon for ARUM from most amendments. Experiments were carried out at Dearborn to determine decomposition rates of cellulose exposed to acidic seepage water.

Cellulolytic capability of the decomposer community was determined by the Remazol Brilliant Blue (RBB) dye-assay (Moore et al. 1979). Stamm et al. (1961) described RBB as a dye which bound to the cellulose molecule and is released quantitatively in proportion to glucose moieties. In the field it is easier to measure the dye remaining bound to the residual cellulose by extraction in hot alkali.

Nylon screen bags containing RBB-stained cellophane strips were placed in the top and bottom level of the Makela reactors. After a 12 month period, bags were removed and cellulose decomposition determined.

The percent of cellulose decomposition was determined by measuring the loss of stain relative to reference RBB stained cellophane strips (control films). The absorbency reading of the dye extracts from the reference RBB stained cellophane strips were very reproducible (0.177 and 0.167).

The results are summarized in Table 31. The percentages of cellulose decomposition estimated by the Remazol Brilliant Blue method in reactor #1 were 66 and 61%, and for #3 were 67% and 44% for the top and bottom levels, respectively. However, the percent of cellulose decomposition that occurred in Makela reactor #2 was much lower; 33% and 34% at top and bottom levels.

As shown in Table 31, reactor #2 was exposed to a longer period of acidic seepage flow than the other 2 reactors. This long period of exposure to acid resulted in inhibition of the cellulose decomposition. Although it was static for 2 months before the nylon bags containing RBB stained cellophane were removed, the community of cellulose degraders did not recover, resulting in the low percent of cellulose decomposition. Sequential nutritional analyses of amendment with and without exposure to Makela acidic seepage water were performed. The procedure involved a number of extraction steps which

	% Of Cellulose Decomp-osition	Profile Of Reactor Treatment
Reactor	66	(i) Static for 2 months (ii) Acidic seepage pumped into reactor at rate of 250 mL/day for 23 days (iii) Static for 6 months (iv) Acidic seepage pumped at rate of 100 mL/day for 27 days (v) Static for 2 months
Makela Reactor #1 Top Port		
Makela Reactor #1 Bottom Port	61	
Makela Reactor #2 Top Port	33	(i) Static for 4.0 months (ii) Acidic seepage pumped into reactor at rate of 100 mL/day for 121 days (iii) Static for 3.5 months
Makela Reactor #2 Bottom Port	34	
Makela Reactor #3 Top Port	67	(i) Acidic seepage pumped into reactor at rate of 500 mL/day for 5 days (ii) Static for 1.5 months (iii) Acidic seepage pumped into reactor at rate of 100 mL/day for 57 days (iv) Static for 5 months (v) Acidic seepage at rate of 100 mL/day for 21 days (vi) Static for 2 months
Makela Reactor #3 Bottom Port	44	

Note: Nylon screen bags containing Remazol Brilliant Blue (RBB) stained cellophane strips (1 cm x 5 cm) were placed in the top and bottom level of the reactor. After a time period of 12 months, the bags were analyzed for the percent of cellulose decomposition. This was determined by measuring the loss of stain relative to reference RBB stained cellophane strips taken from the same dye batch as the test strips. The absorbance reading of the dye extracts from duplicate reference RBB stained cellophane strips were 0.177 and 0.167.

Table 31: Cellulose Decomposition in Makela Water Column Reactors Estimated by Remazol Brilliant Blue Method

Amendment	Composition of Amendment				
	% Loss From Acetone Extraction (Includes Lipids And Resins)	% Loss From HCl Reflux (Includes Soluble Sugars, Starch, Amino Acids And Hemicellulose)	% Loss From H_2SO_4 Digestion (Includes Cellulose)	% Remaining as Lignin, Cutin, Silica And Minerals	% Total Degradables
Control: Straw (analysis #1)	6	33	20	41	59
Control: Straw (analysis #2)	6	33	20	41	59
Control: Flax (analysis #1)	8	38	17	37	63
Control: Flax (analysis #2)	11	38	27	35	65
Straw/flax amendment from Makela reactor #2 (analysis #1)	5	33	4	58	42
Straw/flax amendment from Makela Reactor #2 (analysis #2)	4	33	3	56	40

Table 32: Sequential Nutritional Analyses of Amendment Following a 12 Month ARUM Operation in Makela Acidic Seepage Water

removed the various constituents of the amendment. The results of the analyses are summarized in Table 32.

The percentage of rapidly degradable material (33-38%; sugars, amino acids, and hemicellulose) was unaffected by exposure to acidic seepage water. The percentage of slowly degrading material (cellulose) was much lower (3-4% compared to 17-20%) with exposure to the acidic water.

The results demonstrated that the percent of material resistant to biodegradation following exposure to Makela acidic seepage water did increase from 35-41% (control amendment) to 56-58%. This is expected as the amendment is degraded by the ARUM process.

To test these decomposition rates in the field, decomposition experiments were initiated in the Makela Cell 3 and in Straw Pond (Denison) in 1990. It was expected that cellulolytic activity would be significantly lower in the field than in the lab, so the decomposition bags have not yet been harvested. The initial weights of all materials are presented in Table 33. Methodology for these experiments is described in Appendix 2.

4.4.3 Comparison of SRB enumeration methods

Sulphate-reducers are one of the most important microbial groups of the ARUM process, but, their identification and enumeration present methodological problems. In the first

report several media for SRBs were evaluated, with no clearly superior medium being found. Therefore, continued efforts were made to improve the culture methods, and identify enumeration methods for field use. Comparisons of the Conoco Rapidchek® Sulphate Reducing Bacteria (SRB) Detection System versus conventional cultural media were performed.

The Conoco Rapidchek® Detection System uses specific antibodies to detect the presence of SRBs. However, the Rapidchek® System is able to eliminate chemical interferences by sample pre-treatment steps. In addition, the Rapidchek® System is convenient and takes only 20 minutes. It is also able to detect difficult-to-culture strains.

Therefore, Rapidchek® test results may give higher estimated numbers than the culture media method.

Various ARUM water and amendment samples were analyzed for the presence of SRB by both test methods (Table 34). The Rapidchek® test showed higher or equal numbers of SRBs compared to the cultural test method (Postgate B media) in all samples except sample #4 taken from Buchans Oriental East limnocorral site F sawdust. Comparison tests on this sample have been repeated and are currently in progress.

Sample	Wet Weight (g)	Dry Weight 24 hrs (g)	Dry Weight 48 hrs (g)	Weight H2O (g)	% H2O Avg N=3	SD
Makela Peat	19.315	11.074	10.976	8.339		
	18.434	10.586	10.348	8.053	42.722	1.02
	18.781	11.188	11.023	7.758		
Denison Peat	16.575	9.93	9.604	6.971		
	18.476	10.705	10.725	7.746	42.716	1.026
	22.361	12.948	12.485	9.876		
Makela Alfalfa	2.023	1.472	1.496	0.527		
	4.949	4.312	4.34	0.61	11.498	0.682
	6.45	5.671	5.665	0.743		
Denison Alfalfa	6.046	5.269	5.132	0.914		
	6.234	5.45	5.442	0.792	13.903	0.985
	5.815	4.995	5.008	0.807		
Makela Sawdust	5.526	4.375	4.361	0.409		
	4.837	5.384	5.051	0.474	6.913	2.582
	6.515	4.728	4.435	0.231		
Dension Sawdus	16.086	14.317	14.237	1.849		
	17.949	16.472	16.323	1.627	10.51	1.046
	18.177	16.262	16.182	1.994		
Makela Straw	14.911	4.961	4.533	10.377		
	12.295	2.68	2.304	9.992	72.421	6.388
	15.011	5.449	5.044	9.968		
Denison Straw	6.515	4.674	4.34	2.175		
	6.127	4.021	3.753	2.374	38.161	3.689
	7.308	4.496	4.212	3.095		
Makela Cattails	14.35	2.911	2.781	11.57		
	15.321	3.145	2.986	12.334	75.729	6.84
	9.385	3.346	3.185	6.199		

Table 33: Weights of Organic Matter Placed in Test Areas in 1990

	Sample Description	Rapidchek® SRB Detection System (Sulphate Reducing Bacteria per mL)	Postgate B Media (Sulphate Reducing Bacteria per mL)
1	Denison water column reactor #3 (blackening observed)	10^4	10^4
2	Denison water column reactor (no evidence of blackening and no alkalinity generation produced for 1.5 years)	$<10^3$	10^2
3	Selbaie C amendment	10^5	10^4
4	Buchans Oriental East limnocorral site F sawdust	10^3	10^5
	Buchans Oriental East limnocorral site F sawdust diluted 10X	$<10^3$	(10^4)*
5	Buchans Oriental East P. amendment behind curtain	10^3	10^3
	Buchans Oriental East P. amendment behind curtain diluted 10X	$<10^3$	(10^2)*
6	Makela arumator site 3 amendment	$<10^3$	10^2

*Calculated from results of tests on undiluted sample

Table 34: Comparison of Sulphate Reducing Bacteria Enumeration Methods

4.4.4 Alkalinity-producing reactions of ARUM

Biological alkalinity-producing reactions occurring in lakes and sediments have been listed after Lerman and Stumm, (1989), Davison and Woof, (1990), and Mills Bell and Herlihy, (1989), and are summarised below. Any of these may occur during the ARUM process.

Iron reduction
Carbohydrate as carbon source (10):

$(CH_2O)...+4Fe(OH)_3 \rightarrow CO_2+4Fe^{2+}+3H_2O+8OH^-$ Equation R1.1 (10)

$(CH_2O)...+4FeO(OH)+8H^+ \rightarrow CO_2+4Fe^{2+}+7H_2O$ Equation R1.2 (11)

Glucose as carbon source and lactate production

$6(CH_2O)+FeO(OH)+H_2O \rightarrow 3CO_2+Fe^{2+}+OH^-+CH_3CHOHCOO^-+3.5\ H_2$
Equation R1.3 (12)
Lactate as carbon source

$CH_3CHOHCOO^-+FeO(OH)+H_2O \rightarrow CO_2+Fe^{2+}+CH_3COO^-+CO_2+H_2+2OH^-$
Equation R1.4 (12)

Manganese reduction
Carbohydrate as carbon source

$(CH_2O)...+2MnO_2+H_2O \rightarrow CO_2+2Mn^{2+}+4OH^-$ Equation R2.1 (10)

Glucose as carbon source and lactate production

$6(CH_2O)+MnO_2 \rightarrow 3CO_2+Mn^{2+}+CH_3CHOHCOO^-+3/2H_2+OH^-+2H_2O$ Equation R2.2 (12)

Lactate as carbon source

$CH_3CHOHCOO^-+H_2O+MnO_2 \rightarrow CO_2+Mn^{2+}+CH_3COO^-+2OH^-+(H)$ Equation R2.3 (12)

Ammonia production

Ammonification of organic matter with methane production

$(CH_2O)_{106}(NH_3)_{16}+16H_2O \rightarrow 37CO_2+53CH_4+16NH_4^+ +16HCO_3^-$ Equation R3.1 (10)

$(CH_2O)_{106}(NH_3)_{16}+106O_2+16H^+ \rightarrow 106CO_2+16NH_4^+ +106H_2O$ Equation R3.2 (11)

Nitrate ammonification with carbohydrate as carbon source

$2(CH_2O)...+NO_3^- +2H^+ \rightarrow 2CO_2+NH_4^+ +H_2O$ Equation R3.3 (11)

Nitrate ammonification with glucose as carbon source

$6(CH_2O)+3NO_3^- +3H^+ \rightarrow 6CO_2+3NH_4^+ +3OH^-$ Equation R3.4 (12)

Amino acid fermentation (Strickland reaction)

$CH_3CH(NH_2)CO_2H+2H_2NCH_2CO_2H \rightarrow CO_2+3NH_4^+ +3CH_3COO^-$ Equation R3.5 (12)

Amino acid fermentation (single species reaction)

$HOCH_2CH(NH_2)COOH \rightarrow CH_3COCOO^- +NH_4^+$ Equation R3.6 (12)

Sulphate reduction

Carbohydrate as carbon source with FeS formation

$106(CH_2O)...+48SO_4^{2-} +48Fe(OH)_3 \rightarrow 48FeS+106CO_2+132H_2O+96OH^-$ Equation R4.1 (10)

Carbohydrate as carbon source

$(CH_2O)...+0.5SO_4^{2-} \rightarrow CO_2+0.5H_2O+0.5HS^- +0.5OH^-$ Equation R4.2 (10)

$2(CH_2O)...+SO_4^{2-} +2H^+ \rightarrow 2CO_2+H_2S+2H_2O$ Equation R4.3 (11)

Lactate as carbon source

$CH_3CHOHCOO^- +H_2+SO_4^{2-} \rightarrow H_2S+CO_2+CH_3COO^- +2OH^-$ Equation R4.4 (12)

Denitrification

Organic matter as carbon source

$(CH_2O)_{106}(NH_3)_{16}...+94.4NO_3^- +94.4H^+ \rightarrow 55.2N_2+106CO_2+177.2H_2O$ Equation R5.1 (10)

Carbohydrate as carbon source

$(CH_2O)...+4NO_{-3}+4H^+ \rightarrow 5CO_2+2N_2+7H_2O$ Equation R5.2 (11)

Glucose as carbon source

$6(CH_2O)+4.8NO_3^-+4.8H^+ \rightarrow 6CO_2+2.4N_2+8.4H_2O$ Equation R5.3 (12)

Photosynthesis
Assimilation of nitrate

$106CO_2+16NO_3^-+HPO_4^{2-}+SO_4^{2-}+106H_2O+20H^+ \rightarrow (CH_2O)_{106}(NH_3)_{16}(H_3PO_4)H_2S+140O_2$ Equation R6.1 (10)

$106CO_2+16NO_3^-+HPO_4^{2-}+122H_2O+18H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P+138O_2$ Equation R6.2 (12)

Estimates of the contributions of the reactions described above to alkalinity-generation are listed in Table 35.

For Denison acidic seepage water, the amount of alkalinity produced by each process was first calculated by measuring the amount of sulphate and iron that had been reduced and the amount of ammonia produced at the end of 4 months of operation. Next, the ranges of meq of alkalinity produced were calculated from Table 35. The results are summarized in Table 36. Sulphate reduction accounted for 31 - 56.5% of total alkalinity. Iron reduction contributed 41% of total alkalinity. Ammonia production generated 2.5 -

Reaction Type	Reaction #1 Test		Alkalinity Contribution*
1. Iron reduction		(a)	For carbon source consumed
	R1.1		270 equivalent alkalinity per kg of carbohydrate
	R1.2		270 equivalent alkalinity per kg of carbohydrate
	R1.3		11 equivalent alkalinity per kg of glucose
	R1.4		22 equivalent alkalinity per kg of lactate
		(b)	For ferric iron consumed
	R1.1		36 equivalent alkalinity per kg of Fe^{3+}
	R1.2		36 equivalent alkalinity per kg of Fe^{3+}
	R1.3		36 equivalent alkalinity per kg of Fe^{3+}
	R1.4		36 equivalent alkalinity per kg of Fe^{3+}
2. Manganese reduction		(a)	For carbon source consumed
	R2.1		130 equivalent alkalinity per kg of carbohydrate
	R2.2		11 equivalent alkalinity per kg of glucose
	R2.3		22 equivalent alkalinity per kg of lactate
		(b)	For each MnO_2 reduced
	R2.1		23 equivalent alkalinity per kg of MnO_2
	R2.2		23 equivalent alkalinity per kg of MnO_2
	R2.3		23 equivalent alkalinity per kg of MnO_2
3. Ammonia production		(a)	For carbon source consumed
	R3.1		9.3 equivalent alkalinity per kg organic matter (methane produced)
	R3.2		9.3 equivalent alkalinity per kg organic matter
	R3.3		100 equivalent alkalinity per kg carbohydrate (nitrate ammonification)
	R3.4		50 equivalent alkalinity per kg glucose (nitrate ammonification)
	R3.5		37 equivalent alkalinity per kg amino acids (Strickland)
	R3.6		20 equivalent alkalinity per kg (single amino acids)
		(b)	For ammonia produced
	R3.1		120 equivalent alkalinity per kg ammonia produced
	R3.2		120 equivalent alkalinity per kg ammonia produced
	R3.3		180 equivalent alkalinity per kg ammonia produced
	R3.4		180 equivalent alkalinity per kg ammonia produced
	R3.5		120 equivalent alkalinity per kg ammonia produced
	R3.6		120 equivalent alkalinity per kg ammonia produced
4. Sulphate reduction		(a)	For carbon source consumed
	R4.1		30 equivalent alkalinity per kg carbohydrate (FeS formation)
	R4.2		17 equivalent alkalinity per kg carbohydrate (FeS formation)
	R4.3		30 equivalent alkalinity per kg carbohydrate (FeS formation)
	R4.4		34 equivalent alkalinity per kg lactate (FeS formation)
		(b)	For sulphate consumed
	R4.1		20 equivalent alkalinity per kg SO_4^{2-}
	R4.2		10 equivalent alkalinity per kg SO_4^{2-}
	R4.3		20 equivalent alkalinity per kg SO_4^{2-}
	R4.4		30 equivalent alkalinity per kg SO_4^{2-}
5. Denitrification		(a)	For carbon source consumed
	R5.1		27 equivalent alkalinity per kg organic matter
	R5.2		27 equivalent alkalinity per kg carbohydrate
	R5.3		27 equivalent alkalinity per kg carbohydrate
		(b)	For nitrate consumed
	R5.1		16 equivalent alkalinity per kg NO_3^-
	R5.2		16 equivalent alkalinity per kg NO_3^-
	R5.3		16 equivalent alkalinity per kg NO_3^-
6. Photosynthesis	R6.1		12 equivalent alkalinity per kg plant produced
	R6.2		5.8 equivalent alkalinity per kg plant produced

*Alkalinity = $[HCO_3^-]+2[CO_3^{2-}]+[RCOO^-]+[OH^-]-[H^+]$ from (3)

Table 35: Contribution of Reactions to Alkalinity

Microbial Processes	Number Of Milliequivalents Alkalinity Produced	% Of Total
Sulphate reduction (Table 35, (b) R4.1 - R4.4)	12 - 22	31 - 56.5
Iron reduction (Table 35, (b) R1.1 - R1.4)	16	41
Ammonia production (Table 35, (b) R3.1 - R3.6)	1 -1.5	2.5 - 4.0
Other Processes (Table 35)	0 -10	0 - 26

Notes:

1. This analysis was conducted on Denison water column reactor #2 after 4 months of ARUM initiation in static operation.
2. Number of milli equivalents generated during neutralization process was equal to 39.
3. Methane levels of 4300 ppm was measured in the headspace of the reactor.
4. The amount of alkalinity produced by each process was calculated first by measuring the amount of sulphate and iron reduced and ammonia produced at the end of the 4 month operation. Next, the range of milli equivalents of alkalinity produced was calculated from Table 35 which had been derived from the alkalinity reactions previously listed.

Table 36: Contribution of Microbial Processes to Alkalinity Generation in Denison Water

4.0% of total alkalinity produced. Other microbial processes listed in Table 24 contributed 0 - 10 meq of alkalinity, representing 0 - 26% of total alkalinity.

Estimates of carbohydrate requirements for alkalinity-generation can also be determined from Table 24. The amount of alkalinity produced during Makela reactor #2 flow experiment was 13.7 meq (Table 37). Therefore, if iron reduction (Table 35, R1.1, R1.2) accounted for the total alkalinity generated, 0.05 g of carbohydrates would be required. Similarly, if manganese reduction, ammonia production and denitrification reactions (Table 35, R2.1, R3.3, R5.2 and R5.3) contributed to alkalinity, 0.10 g to 0.51 g of carbohydrates would need to be consumed for alkalinity-generation to occur. Carbohydrate requirements for sulphate reduction reactions (Table 35, R4.1 - R4.3) would be 0.46 g to 1.24 g. One can also determine whether the amount of amendment (carbohydrate) that was added was sufficient to generate alkalinity by the various microbial processes. For example, approximately 30 g of straw/flax amendment was added to Makela reactor #2. A sequential analysis of the amendment following a 12 month ARUM operation was determined. The results demonstrated that approximately 40% of the amendment was degradable (Table 32). Therefore, 12 g of the amendment was available for degradation. Since 12 g is far in excess of the carbohydrate requirements (calculated in the previous paragraph), it can be assumed that the amount of amendment added to the reactor was sufficient to generate alkalinity.

Carbohydrate required for the generation of alkalinity in Denison acidic seepage was also estimated. Since the amount of alkalinity produced by Denison reactor #3 experiment

Days of Operation	pH	Volume Treated (mL)	Meq of Alkalinity Produced	Cumulative Volume Treated (mL)	Cumulative Meq Produced
0	7.53	0	0.0	0	0
1	6.80	100	0.210	100	0.210
2	6.85	100	0.20	200	0.41
5	6.77	300	0.610	500	1.02
8	6.62	300	0.59	800	1.61
12	6.62	400	0.79	1200	2.40
15	6.30	300	0.58	1500	2.98
19	6.02	400	0.73	1900	3.71
22	5.85	300	0.54	2200	4.25
27	5.30	500	0.86	2700	5.11
29	5.77	200	0.34	2900	5.45
33	5.84	400	0.70	3300	6.15
36	6.00	300	0.54	3600	6.69
40	5.87	400	0.71	4000	7.40
43	5.83	300	0.53	4300	7.93
47	5.40	400	0.69	4700	8.62
57	4.86	1000	1.60	5700	10.22
61	4.32	400	0.58	6100	10.80
64	4.20	300	0.41	6400	11.21
72	4.25	800	1.08	7200	12.29
78	4.34	600	0.83	7800	13.12
82	3.76	400	0.53	8200	13.65

Table 37: Cumulative Alkalinity Generation During Makela Reactor #2 Flow Experiment

was greater than that produced from the Makela flow experiment, the carbohydrate requirements would be greater. It was calculated that 63.6 meq of alkalinity was produced by Denison reactor #3 flow experiment (Table 38). Therefore, if iron reduction (Table 35, R1.1, R1.2) represented total alkalinity produced, 0.23 g of carbohydrate would be required; 0.49 g to 2.12 g of carbohydrate would need to be consumed if manganese reduction, ammonia production and denitrification contributed to alkalinity (Table 35, R2.1, R3.3, R5.2, and R5.3). Sulphate reduction reactions required 2.12 g to 3.70 g of carbohydrates (Table 35, R4.1 - R4.3) to generate alkalinity. Again, the amendment requirement was easily satisfied by the amount which had been added to the reactor.

Days of Operation	pH	Volume Treated (mL)	Meq of Alkalinity Produced	Cumulative Volume Treated	Cumulative Meq Produced
0	6.00	0	0.0	0	0.0
2	5.93	200	7.40	200	7.4
6	5.78	400	14.40	600	21.8
14	5.28	800	26.40	1400	48.2
21	3.35	700	15.40	2100	63.6

Table 38: Cumulative Alkalinity Generation During Makela Reactor #3 Flow Experiment

5.0 CONCLUSIONS

This report is essentially a data analysis report describing the chemical and physical conditions of the Test Cell System. Microbial alkalinity-generation and its controlling factors are addressed in the laboratory and the field. For ease of reference, the conclusions are presented in point form.

Hydrology of Makela Test Cells

- The pH in the Test Cell System in 1990 differed significantly from that in 1989/1990. Oxidation and subsequent hydrolysis of ferrous iron compounds is now restricted to Cell 1 and the pH drops 2 - 2.5 units prior to Cell 2. The rate of change within Cell 1 is a function of the flow rate through the cell. Low flow rates result in lower pH values in Cell 1. The acidity of the cell water increased from July to August, 1990. Significant changes in the magnitude of the acidity correlate well with the dissolved iron content.

- Measurements of pH, Eh, alkalinity, and acidity change significantly when determined on site in the field and later after transport to the laboratory. The changes are related to the type of water, i.e. AMD seepage, groundwater and ARUMator water. However, the changes are sufficiently large that errors could be introduced to the study of the effectiveness of the treatment system and to geochemical simulation, if laboratory values are used.

- In 1990, suspended iron oxides/hydroxides were deposited in Cell 1 and not carried across the cell system as occurred during 1989/1990. pH and pE profiles in Cell 1 show that the magnitude of the two parameters and the change within the Cell is a function of the flow rate through the cell. pH and pE profiles in all the other cells and ponds showed little or no change on August 8, 1990. Settling experiments conducted on precipitates collected from the seepage ditch, Cell 1, Cell 2, and Pond A respectively, show a substantial increase in the settling rate, which appears to be in part related to a change in the type and degree of crystallization of the iron minerals.

- Biological activity between August 8 and 24, 1990 appears to have been the main cause of a significant increase in the pH in the bottom of Cell 4. A decrease of one order of magnitude in Eh was measured in one locality in Cell 4 between the two August 1990 sampling dates. This also appears to be caused by biological activity.

- The hydraulic conductivity of the sediments underlying the cells varies from 0.00012 to 0.0067 cm/sec. A potential exists for small quantities of ground water discharge into Cell 3, Pond B, and Cell 4. Ground water recharge is occurring under Cell 1 and possibly Cell 2.

- Comparing the various sample stations through the Test Cell System shows that concentrations of Mg, Na, Ni, P, S, and Sr remain more or less constant; Ca, K, Co, and Si increase slightly; Al, Mn, Cu, and Zn increase significantly; and Fe decreases through the cell system. It appears that rising water levels, in combination with chemically active cell walls, are the cause of variations in the ionic concentration of most elements in the cells and ponds between sample stations and between sampling dates. The permeable gravel berms show only consistent changes for Fe (decrease), and Al and Si (increase) through the cell system. Iron is precipitated in the berms, while the increase in Al and Si is caused by dissolution of feldspars.

- Increased [Ni] in the feed water and cell waters between July 1989 and August 1990 was probably not caused by the discharge of ground water into the cell system; groundwater samples generally had lower [Ni] values.

- The chemistry of the ground water obtained from the piezometers shows seasonal changes in concentrations of elements, except for P-5 and P-7, which reflect the effect of groundwater recharge from Cell 1 and Cell 2 water. Water samples from piezometer P-7 appear to reflect mixing of groundwater with infiltration from Cell 1 or Cell 2.

Microbiological ecology of ARUM

- **Field ARUMators**: The replacement of acidity by alkalinity in AMD seepage water has been achieved in ARUMators in the field by the ARUM process without the use of conventional neutralizing agents. It can be concluded, given the consistent trends in all ARUMators studied, that the onset of alkalinity-generating microbial activity may be delayed, but not inhibited in any of the conditions tested to date. The delay may be dependant on the composition of the treated AMD. Alkalinity-generation can be achieved in seepages with high concentrations of heavy metals and with high acidities. The ARUM process is presently being tested at flows of 3 to 5 L/min in a Test Cell System installed at the Copper Cliff (Makela) tailings area.

- **Laboratory ARUMators (Flow Reactors)**: Makela: ARUM was achieved in flow-through reactors at flow rates of 100 mL/day using Makela acidic seepage. The longest Makela flow-through experiments operated continuously for 121 days before failing (pH dropping below 4). During this time, nickel was usually not detected (detection limit = 0.2 mg/L), sulphate-reduction was occurring and ferrous iron levels in the effluent were low. Introduction of sodium nitrate to the Makela water column reactor stimulated alkalinity-generation and further maintained the ARUM process.

- Denison: Alkalinity-generation could be initiated in water column reactors containing Denison mine acidic seepage water with amendments of iron metal and flax. A bench-scale flow operation was unsuccessful using Denison acidic seepage water at flow rates of 100 mL/day. During flow operation with Denison acidic seepage water, the ARUM process continued for a 2 to 3 week period (approximately equal to the fluid retention time for the flow operation) before the pH fell below 4.0. Following Denison flow operations, microbial population levels remained constant, except for the VFA (volatile fatty acid) producer population whose numbers decreased. It is possible that the VFA producer population was susceptible to the effects of acidic seepage water.

Both Makela and Denison water column reactors, which had previously been exposed to acidic seepage during flow operation and failed, were able to regenerate alkalinity during a static period.

- **Other Laboratory Experiments**: Successful initiation of alkalinity-generation in 40 mL glass vials containing acidic seepage from Denison was demonstrated with the following amendments (i) algae; (ii) 200 ppm $Ca(NO_3)_2$; (iii) 500 ppm Na_2SO_3; (iv) 400 ppm $NaNO_3$; (v) oxidized iron metal. Iron, alone, and flax, alone, did not significantly contribute to alkalinity-generation in the absence of micro-organisms.

- Pure cultures of alkalinity-generating micro-organisms including sulphate-reducing bacteria, iron-reducing bacteria and ammonifier bacteria were isolated and are presently being maintained.

- Evidence suggests that sulphate-reducing bacteria alone are able to raise the pH of highly acidic seepage water (Denison) from less than 3.0 to pH 5.91.

- A colourimetric method using ferric hydroxamate was found useful as a simple procedure for the determination of total organic acids.

- A volatile fatty acid producer culture medium was developed.

- An evaluation of sulphate-reducing bacterial enumeration methods was conducted. Comparisons of the Conoco Rapidchek® SRB Detection System versus conventional test media were made. The Rapidchek® System is a simple, effective method which gave comparable semi-quantitative results.

- The cellulolytic capability of the cellulose-degrading population was determined by testing the capability of the micro-organisms to degrade cellophane stained by Remazol brilliant blue (RBB). The percent of cellulose decomposition that occurred in Makela water column reactor #2 following a 12 month ARUM operation was approximately 33%.

- A simplified version of a forage fibre analysis method was used to determine the percent of degradable material available for biodegradation. Sequential nutritional analysis of amendment by this technique appears promising but requires validation by further experiments.

- Biological alkalinity producing reactions were summarized from the literature. Carbon requirements for each of these reactions were calculated. The percent contribution of these microbial processes to alkalinity-generation was then calculated for an experiment in which amendment was exposed to Denison acidic seepage water. Sulphate and iron reduction accounted for most of the alkalinity-generation (31-56.5% and 41% respectively). In addition, examples of the range of total carbohydrate requirements for alkalinity-generation were calculated for both Denison and Makela acidic seepage water treatment experiments. With both acidic seepages, available carbohydrate released from the amendment greatly exceeded that theoretically required for alkalinity-generation. ARUM has been demonstrated both in the flow-through reactors in the laboratory with Makela and Denison acidic seepage water and in the field at Makela and Denison in larger (170 L) ARUMators. Ongoing studies in the field ARUMators are characterizing the alkalinity-generation, and laboratory experiments are seeking the optimal conditions for alkalinity-generation in Makela and Denison acidic seepage waters.

6.0 REFERENCES

Note: Reference numbers referred to in the text in Section 4 **(1) - (12)**

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APPENDICES

APPENDIX 1: TECHNICAL DATA

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APPENDIX 2: METHODS

APPENDIX 1

TECHNICAL DATA

SAMPLE DATE		21/08/89	21/08/89	21/08/89	21/08/89	21/08/89	21/08/89	21/08/89	21/08/89
ASSAYERS CODE		Metals lost:			Max 89.41%		Min 85.07%		
SAMPLING LOCATION		Seep Water	S-Pond 1 Inflow	S-Pond 1 Outflow	Cell 1 Inflow	Cell 1 Outflow	S-Pond 2 Inflow	S-Pond 2 Outflow	Cell 2 Inflow
PROC.CODE	FA	1	2	3	4	5	6	7	8
Temperature, C		17	16.4	16	15.5	16.4	15.1	16.8	17.8
pH, units		6.62	5.5	5.75	5.66	5.52	5.48	5.51	5.25
Eh, mV									
Cond., micromho/cm		1700	2800	3000	2700	3000	2450	3100	3050
Ferric (ppm)		0	0	0	0	0	0	0	0
Ferrous (ppm)		220	260	260	250	250	250	250	240
Elements	At.Wght.	mg/L							
Ag	107.8680	0.0046							
Al	26.9815	0.0646							
As	74.9216	0.0287	0.0315		0.0384		0.0374		0.0328
B	10.8100	0.210	0.251		0.261		0.292		0.268
Ba	137.3300	0.0173	0.0171		0.0170		0.0179		0.0180
Be	9.0122	0.0006	0.0006		0.0008		0.0006		0.0008
Bi	208.9804	0.0208							
C	12.0110								
Ca	40.0800	408	440		432		468		476
Cd	112.4100	0.0026							
Ce	140.1200								
Co	58.9332	0.1760	0.3650		0.3660		0.3920		0.4060
Cr	51.9960	0.0066	0.0091		0.0095		0.0093		0.0096
Cu	63.5460	0.0150	0.0697		0.0625		0.0547		0.0566
Fe	55.8470	155	252		233		241		232
K	39.0983								
La	138.9055								
Mg	24.3050	90	144		142		153		156
Mn	54.9380	1.89	3.44		3.40		3.65		3.71
Mo	95.9400								
Na	22.9898	140	144		141		157		152
Nb	92.9064								
Ni	58.7000	5.29	9.60		9.61		10.50		11.10
P	30.9738	0.0885	0.0976		0.0994		0.0830		0.0992
Pb	207.2000	0.0580							
S	32.0600								
Sb	121.7500	0.0708							
Se	78.9600	0.0818							
Si	28.0855								
Sn	119.6900	0.0200	0.0277		0.0248		0.0230		0.0264
Sr	87.6200								
Te	127.6000	0.0954							
Th	232.0381								
Ti	47.9000	0.0261	0.0137		0.0121		0.0114		0.0153
U	238.0290								
V	50.9415	0.0048			0.0047				
W	183.8500								
Y	88.9059								
Zn	65.3800	0.064	0.141		0.137		0.147		0.178
Zr	91.2200								
Chloride	35.453	88.5	41.0		80.5		80.0		83.0
Acidity		340	460		536		563		546
Sulphate	96.06	2600	3010		3010		3070		3110
Ammonia		6.7	7.5		7.9		6.9		7.5
T.S.S.		131	99		77		47		31

SAMPLE DATE	21/08/89	21/08/89	21/08/89	21/08/89	21/08/89	21/08/89
ASSAYERS CODE						
SAMPLING LOCATION	Cell 2 Outflow	Set Pond Inflow	Set Pond Outflow	Cell 3 Inflow	Cell 3 Outflow	System Outflow
PROC.CODE FA	9	10	11	12	13	14
Temperature, C	19.1	19.8	20.1	19.2	19.2	21.2
pH, units	5.19	5.2	5.12	4.6	4.45	4.47
Eh, mV						
Cond., micromho/cm	3350	2980	3350	3290	3260	3300
Ferric (ppm)	0	0	0	0	0	0
Ferrous (ppm)	220	250	240	250	260	240
Elements At.Wght.						
Ag 107.8680						
Al 26.9815						
As 74.9216		0.0355		0.0332		0.0352
B 10.8100		0.281		0.281		0.273
Ba 137.3300		0.0178		0.0167		0.0163
Be 9.0122		0.0005		0.0007		0.0005
Bi 208.9804						
C 12.0110						
Ca 40.0800		471		447		432
Cd 112.4100						
Ce 140.1200						
Co 58.9332		0.3990		0.3880		0.3760
Cr 51.9960		0.0079		0.0072		0.0074
Cu 63.5460		0.0610		0.0649		0.0729
Fe 55.8470		228		210		200
K 39.0983						
La 138.9055						
Mg 24.3050		154		147		141
Mn 54.9380		3.81		3.73		3.60
Mo 95.9400						
Na 22.9898		153		145		142
Nb 92.9064						
Ni 58.7000		11.10		10.70		10.40
P 30.9738		0.1000		0.0987		0.0930
Pb 207.2000						
S 32.0600						
Sb 121.7500						
Se 78.9600						
Si 28.0855						
Sn 118.6900		0.0248		0.0229		0.0252
Sr 87.6200						
Te 127.6000						
Th 232.0381						
Ti 47.9000		0.0124		0.0100		0.0102
U 238.0290						
V 50.9415						
W 183.8500						
Y 88.9059						
Zn 65.3800		0.151		0.151		0.151
Zr 91.2200						
Chloride 35.453		80.5		81.0		85.5
Acidity		513		536		529
Sulphate 96.06		3140		3170		3030
Ammonia		6.8		7.6		7.6
T.S.S.		26		18		16

SAMPLE DATE		28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89
ASSAYERS CODE									
SAMPLING LOCATION		Seep Water	S-Pond 1 Inflow	S-Pond 1 Outflow	Cell 1 Inflow	Cell 1 Outflow	S-Pond 2 Inflow	S-Pond 2 Outflow	Cell 2 Inflow
PROC.CODE	FA	1	2	3	4	5	6	7	8
Temperature, C		11	15	15	15	14	12	13	13
pH, units		6.05	5.45	5.35	4.78	5.23	5.2	5.2	5.13
Eh, mV									
Cond., micromho/cm		2500	3000	3000	3000	3000	2700	2700	2700
Ferrous (ppm)		0	0	0	0	0	0	0	0
Ferric (ppm)		0	0	0	0	0	0	0	0
Elements	At.Wght.	mg/L							
Ag	107.8680	0.0046							
Al	26.9815	0.0646							
As	74.9216	0.0417	0.0413	0.0436	0.0353	0.0462	0.0474	0.0349	0.0363
B	10.8100	0.0360	0.0305	0.2640	0.0510	0.1950	0.1490	0.0797	0.2710
Ba	137.3300	0.0278	0.0255	0.0248	0.0273	0.0243	0.0254	0.0260	0.0234
Be	9.0122	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Bi	208.9804	0.0208	0.0363	0.0267	0.0384	0.0328	0.0260	0.0343	0.0238
C	12.0110								
Ca	40.0800	487	494	500	503	514	510	501	507
Cd	112.4100	0.0104			0.0030			0.0030	
Ce	140.1200								
Co	58.9332	0.2250	0.4020	0.3990	0.4060	0.4130	0.4100	0.4020	0.4090
Cr	51.9960	0.0137	0.0176	0.0173	0.0197	0.0181	0.0181	0.0178	0.0157
Cu	63.5460	0.0647	0.1010	0.0500	0.0588	0.0544	0.0592	0.0601	0.0548
Fe	55.8470	160	223	217	222	227	221	220	222
K	39.0983								
La	138.9055								
Mg	24.3050	111	155	156	157	160	159	156	158
Mn	54.9380	2.43	3.66	3.74	3.42	3.75	3.71	3.65	3.74
Mo	95.9400								
Na	22.9898	143	142	143	144	147	145	144	144
Nb	92.9064								
Ni	58.7000	6.38	9.53	9.51	9.77	10.00	9.89	9.76	10.00
P	30.9738	0.113	0.139	0.140	0.134	0.144	0.124	0.124	0.119
Pb	207.2000	0.0496	0.0579						
S	32.0600								
Sb	121.7500	0.0708	0.0809	0.0744	0.0802	0.0764	0.0754		0.0843
Se	78.9600	0.0818							
Si	28.0855								
Sn	118.6900	0.0259	0.0310	0.0300	0.0491	0.0348	0.0309	0.0293	0.0326
Sr	87.6200								
Te	127.6000	0.0954							
Th	232.0381								
Ti	47.9000	0.0127	0.0150	0.0072	0.0153	0.0150	0.0147	0.0143	0.0096
U	238.0290								
V	50.9415	0.0047	0.0059	0.0054	0.0059	0.0057	0.0060	0.0047	0.0050
W	183.8500								
Y	88.9059								
Zn	65.3800	0.183	0.224	0.219	0.231	0.234	0.220	0.227	0.228
Zr	91.2200								
Chloride	35.453								
Acidity		375	545	505	505	515	535	515	525
Sulphate	96.06	2924.6	3174.8	3305	3113	3252	3085	3019	3102
Ammonia									
T.S.S.		78.4	71.6	27	72	35.8	52	34.6	30.2

SAMPLE DATE		28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89
ASSAYERS CODE							
SAMPLING LOCATION		Cell 2 Outflow	S-Pond 3 Inflow	S-Pond 3 Outflow	Cell 3 Inflow	Cell 3 Outflow	System Outflow
PROC.CODE	FA	9	10	11	12	13	14
Temperature, C		13.5	14	13.5	14	13	13.5
pH, units		4.9	4.9	4.97	4.83	4.61	4.65
Eh, mV							
Cond., micromho/cm		2700	2700	2700	2700	2700	2700
Ferrous (ppm)		0	0	0	0	0	0
Ferric (ppm)		0	0	0	0	0	0
Elements	At.Wght.						
Ag	107.8680						
Al	26.9815						
As	74.9216	0.0544	0.0437	0.0491	0.0416	0.0397	0.0497
B	10.8100	0.1940	0.1180	0.2910	0.2760	0.0972	0.2440
Ba	137.3300	0.0459	0.0257	0.0256	0.0258	0.0333	0.0265
Be	9.0122						
Bi	208.9804	0.0341	0.0294	0.0258	0.0295	0.0319	0.0394
C	12.0110						
Ca	40.0800	518	513	526	528	430	532
Cd	112.4100			0.0028			
Ce	140.1200						
Co	58.9332	1.5100	0.4130	0.4180	0.4210	0.4290	0.4270
Cr	51.9960	0.0174	0.0181	0.0162	0.0172	0.0177	0.0193
Cu	63.5460	0.1250	0.0614	0.0590	0.0599	0.0631	0.0695
Fe	55.8470	222	217	224	224	218	220
K	39.0983						
La	138.9055						
Mg	24.3050	160	158	162	162	163	163
Mn	54.9380	3.89	3.52	3.94	3.99	4.23	4.28
Mo	95.9400						
Na	22.9898	146	145	149	149	149	149
Nb	92.9064						
Ni	58.7000	12.70	10.10	10.40	10.40	10.60	10.50
P	30.9738	0.137	0.113	0.111	0.115	0.109	0.126
Pb	207.2000						0.0559
S	32.0600						
Sb	121.7500	0.0794	0.0770				
Se	78.9600						
Si	28.0855						
Sn	118.6900	0.0319	0.0328	0.0315	0.0314	0.0317	0.0338
Sr	87.6200						
Te	127.6000						
Th	232.0381						
Ti	47.9000	0.0161	0.0157	0.0099	0.0103	0.0136	0.0400
U	238.0290						
V	50.9415	0.0061	0.0064	0.0050	0.0060	0.0049	0.0069
W	183.8500						
Y	88.9059						
Zn	65.3800	0.242	0.231	0.252	0.221	0.278	0.247
Zr	91.2200						
Chloride	35.453						
Acidity		525	525	525	538	515	515
Sulphate	96.06	3208	3130	3046	3046	3208	3241
Ammonia							
T.S.S.		21.7	26.5	22.4	23.8	12.1	22.7

TABLE A-3. CELL WATERS - CHEMISTRY

SAMPLE DATE		28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89	28/09/89
ASSAYERS CODE		1403	1404	1406	1408	1410	1412	1414	1416
SAMPLING LOCATION		Seep Flow	S-Pond 1 Inflow	Cell 1 Inflow	S-Pond 2 Inflow	Cell 2 Inflow	S-Pond 3 Inflow	Cell 3 Inflow	System Disch.
PROC.CODE		FA-1	FA-2	FA-4	FA-6	FA-8	FA-10	FA-12	FA-14
Temperature, C		11.0	15.0	15.0	12.0	13.0	14.0	14.0	13.5
pH, units		6.05	5.45	4.78	5.20	5.13	4.90	4.83	4.65
Eh, mV									
Cond., micromho/cm		2500	3000	3000	2700	2700	2700	2700	2700
Ferrous (ppm)									
Ferric (ppm)									
Elements	At.Wght	mg/L							
Ag	107.8680	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al	26.9815	0.1	0.2	0.5	0.5	0.2	0.2	0.2	0.2
As	74.9216	0.09	0.03	0.3	0.3	0.04	0.05	0.01	0.05
B	10.8100	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Ba	137.3300	0.03	0.03	0.3	0.3	0.04	0.03	0.03	0.03
Be	9.0122	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
Bi	208.9804	0.05	0.02	0.1	0.1	0.04	0.03	0.03	0.01
C	12.0110	1091	676	477	390	290	254	208	137
Ca	40.0800	541	519	527	532	539	543	551	566
Cd	112.4100	0.1	0.07	0.4	0.5	0.1	0.09	0.06	0.09
Ce	140.1200	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.1
Co	58.9332	0.3	0.5	0.7	0.7	0.5	0.5	0.5	0.5
Cr	51.9960	0.06	0.03	0.09	0.1	0.03	0.03	0.02	0.03
Cu	63.5460	0.02	0.06	0.08	0.08	0.06	0.06	0.6	0.07
Fe	55.8470	217	291	290	295	297	296	299	302
K	39.0983	111	114	117	118	118	118	118	121
La	138.9055	0.02	0.03	0.04	0.03	0.04	0.03	0.02	0.03
Mg	24.3050	140	183	185	187	189	191	193	198
Mn	54.9380	2.5	3.6	3.6	3.7	3.7	3.9	4	4.3
Mo	95.9400	0.1	0.04	0.8	1	0.04	0.1	0.01	0.1
Na	22.9898	194	183	185	187	191	192	195	200
Nb	92.9064	0.01	0.01	0.04	0.04	0.01	0.01	0.01	0.01
Ni	58.7000	8.2	11	11	11	11	12	12	12
P	30.9738	4.9	1.1	1.3	1.2	5.2	1.2	1.3	5.1
Pb	207.2000	0.2	0.2	0.3	0.4	0.2	0.2	0.2	0.2
S	32.0600	770	839	834	872	850	859	873	892
Sb	121.7500	0.07	0.08	0.1	0.1	0.08	0.08	0.08	0.08
Se	78.9600	0.03	0.05	0.1	0.2	0.04	0.07	0.05	0.07
Si	28.0855	15	18	19	19	19	19	19	20
Sn	118.6900	0.01	0.01	0.03	0.04	0.01	0.01	0.01	0.01
Sr	87.6200	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
Te	127.6000	0.04	0.02	0.2	0.2	0.02	0.03	0.01	0.03
Th	232.0381	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ti	47.9000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
U	238.0290	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.04
V	50.9415	0.02	0.02	0.04	0.04	0.02	0.02	0.02	0.02
W	183.8500	0.01	0.01	0.06	0.07	0.01	0.01	0.01	0.01
Y	88.9059	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn	65.3800	12	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Zr	91.2200	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03
Chloride	35.453								
Acidity		375	545	505	535	525	525	538	515
Sulphate	96.06	2307	2514	2499	2613	2547	2574	2616	2673
Nitr./Amm									
T.S.S.		78.4	71.6	72	52	30.2	26.5	23.8	22.7

SAMPLE DATE		06/12/89	06/12/89	06/12/89	06/12/89	06/12/89	06/12/89
ASSAYERS CODE		1539	1540	1536	1537	1538	1535
SAMPLING LOCATION		Inflow 0.4C	Inflow 17.6C	Weir 1 0.0C	Weir 1 16.1C	Cell 4 0.0C	Cell 4 15.4C
PROC.CODE		FA	FA	FA	FA	FA	FA
Temp.,C		0.4	17.6	0.0	16.1	0.0	15.4
pH, units		5.79	5.87	4.54	5.36	4.62	4.70
Eh, mV							
Cond. (umhos)		2300	3200	2250	3000	2500	3200
Ferric (ppm)							
Ferrous (ppm)							
Elements	At.Wght.	mg/L					
Ag	107.8680	0.01	0.01	0.01	0.01	0.01	0.01
Al	26.9815	0.01	0.01	0.1	0.01	2.1	1.9
As	74.9216	0.04	0.03	0.08	0.1	0.01	0.01
B	10.8100	0.5	0.4	0.8	0.7	0.5	0.6
Ba	137.3300	0.02	0.02	0.04	0.03	0.06	0.07
Be	9.0122	0.01	0.01	0.01	0.01	0.01	0.01
Bi	208.9804	0.01	0.01	0.01	0.01	0.01	0.01
C	12.0110	428	111	442	290	1111	1003
Ca	40.0800	509	459	559	494	559	524
Cd	112.4100	0.03	0.02	0.07	0.05	0.4	0.4
Ce	140.1200	0.01	0.01	0.02	0.01	0.01	0.03
Co	58.9332	0.3	0.2	0.5	0.4	5	4.7
Cr	51.9960	0.01	0.01	0.04	0.01	0.01	0.03
Cu	63.5460	0.01	0.01	0.06	0.02	3.6	3.1
Fe	55.8470	161	141	197	173	61	56
K	39.0983	93	85	101	86	34	36
La	138.9055	0.01	0.01	0.05	0.01	0.2	0.2
Mg	24.3050	129	117	169	148	226	208
Mn	54.9380	3	2.7	4	3.6	29	26
Mo	95.9400	0.01	0.01	0.01	0.01	0.01	0.01
Na	22.9898	151	140	146	133	169	140
Nb	92.9064	0.01	0.01	0.02	0.01	0.02	0.03
Ni	58.7000	7	6.1	9.8	8.6	177	167
P	30.9738	0.1	0.1	0.2	0.1	0.1	0.2
Pb	207.2000	0.01	0.01	0.1	0.1	0.2	0.3
S	32.0600	889	818	1019	889	1095	1015
Sb	121.7500	0.01	0.01	0.01	0.01	0.02	0.01
Se	78.9600	0.01	0.01	0.01	0.01	0.01	0.01
Si	28.0855	10	9.3	15	13	14	13
Sn	118.6900	0.01	0.01	0.01	0.01	0.01	0.01
Sr	87.6200	0.7	0.6	0.7	0.6	0.9	0.7
Te	127.6000	0.01	0.01	0.03	0.02	0.01	0.03
Th	232.0381	0.01	0.01	0.01	0.01	0.01	0.01
Ti	47.9000	0.01	0.01	0.01	0.01	0.01	0.01
U	238.0290	0.01	0.01	0.01	0.01	0.01	0.01
V	50.9415	0.01	0.01	0.01	0.01	0.02	0.02
W	183.8500	0.01	0.01	0.01	0.01	0.01	0.01
Y	88.9059	0.01	0.01	0.01	0.01	0.2	0.2
Zn	65.3800	0.1	0.3	0.2	0.4	4.8	4.4
Zr	91.2200	0.01	0.01	0.04	0.01	0.01	0.03
Chloride	35.453						
Acidity							
Sulphate	96.06	2664	2451	3053	2664	3281	3041
Ammonia							
T.S.S.							

SAMPLE DATE		06/02/90	06/02/90	06/02/90	06/02/90
ASSAYERS CODE		1566	1567	1568	1569
SAMPLING LOCATION		Cell 1 Inflow	Cell 2 Inflow	Cell 3 Inflow	Cell 4 Inflow
PROC.CODE	FA	1	4	8	12
Temp.		2.7	0.1	0.1	0.3
pH		5.90	4.90	5.28	5.58
Eh, mV					
Cond. (umhos)		2000	2000	2100	2800
Ferric (ppm)		20	40	80	100
Ferrous (ppm)		180	50	40	0
Elements	At.Wght.	mg/L			
Ag	107.868	0.01	0.01	0.01	0.01
Al	26.9815	0.1	0.2	0.1	0.1
As	74.9216	0.01	0.01	0.01	0.01
B	10.8100	0.01	0.01	0.3	0.1
Ba	137.3300	0.01	0.01	0.01	0.01
Be	9.0122	0.01	0.01	0.01	0.01
Bi	208.9804	0.07	0.01	0.01	0.08
C	12.0110	1244	884	4699	6221
Ca	40.0800	492	453	474	520
Cd	112.4100	0.01	0.01	0.01	0.01
Ce	140.1200	0.01	0.01	0.01	0.01
Co	58.9332	0.01	0.01	0.01	0.6
Cr	51.9960	0.01	0.01	0.01	0.01
Cu	63.5460	0.01	0.01	0.01	0.04
Fe	55.8470	158	32	94	63
K	39.0983	77	47	40	0.1
La	138.9055	0.01	0.01	0.01	0.01
Mg	24.3050	142	197	223	204
Mn	54.9380	2.5	3.6	16	42
Mo	95.9400	0.06	0.01	0.01	0.1
Na	22.9898	176	159	214	177
Nb	92.9064	0.01	0.01	0.01	0.01
Ni	58.7000	6	19	42	16
P	30.9738	0.7	0.01	0.01	0.07
Pb	207.2000	0.01	0.01	0.01	0.01
S	32.0600	755	746	840	718
Sb	121.7500	0.1	0.01	0.01	0.01
Se	78.9600	0.11	0.01	0.01	0.2
Si	28.0855	16	15	16	11
Sn	118.6900	0.01	0.01	0.01	0.07
Sr	87.6200	1.6	1.4	1.4	2.4
Te	127.6000	0.01	0.01	0.01	0.04
Th	232.0381	0.01	0.01	0.01	0.01
Ti	47.9000	0.01	0.01	0.01	0.01
U	238.0290	0.01	0.01	0.01	0.01
V	50.9415	0.01	0.01	0.01	0.01
W	183.8500	0.01	0.01	0.01	0.01
Y	88.9059	0.01	0.01	0.01	0.01
Zn	65.3800	0.01	0.01	0.06	0.2
Zr	91.2200	0.01	0.01	0.01	0.01
Chloride	35.453				
Acidity (lab)		500	500	550	600
Sulphate	96.06	2262	2235	2517	2151
Ammonia					
T.S.S.					

TABLE A-6. CELL WATERS - CHEMISTRY

SAMPLE DATE		28/03/90	28/03/90	28/03/90	28/03/90	28/03/90	28/03/90	28/03/90	28/03/90
ASSAYERS CODE		1620/31	1621/32	1622/33	1623/34	1619/30			
SAMPLING LOCATION		System Inflow	Cell 2 Inflow	Cell 3 Inflow	Cell 4 Inflow	S/Pipe Cell 4	Bermwall 160 cm t	Bermwall 210 cm m	Bermwall 310 cm b
PROC.CODE	FA	1	4	8	12	14			
Temp.		5.0	5.0	5.0	5.0	2.0	1.3	1.7	2.4
pH		5.11	3.31	4.27	5.10	5.40			
Eh, mV									
Cond. (umhos)		2900	2600	1100	800				
Ferric (ppm)		0	10	25	0	0			
Ferrous (ppm)		200	80	30	20	20			
Elements	At.Wght.	mg/L							
Ag	107.8680	0.01	0.01	0.01	0.01	0.01			
Al	26.9815	0.7	2.8	2.4	1.1	0.01			
As	74.9216	0.09	0.01	0.01	0.01	0.01			
B	10.8100	0.01	0.01	0.01	0.01	0.01			
Ba	137.3300	0.04	0.03	0.03	0.02	0.01			
Be	9.0122	0.01	0.01	0.01	0.01	0.01			
Bi	208.9804	0.01	0.01	0.01	0.01	0.01			
C	12.0110								
Ca	40.0800	567	465	496	472	315			
Cd	112.4100	0.02	0.01	0.01	0.03	0.01			
Ce	140.1200	0.01	0.01	0.01	0.01	0.01			
Co	58.9332	1.4	0.9	1.1	1.1	0.4			
Cr	51.9960	0.1	0.03	0.03	0.01	0.02			
Cu	63.5460	1.2	1.6	1.9	1.5	0.03			
Fe	55.8470	139	55	17	11	11			
K	39.0983	162	133	120	121	17			
La	138.9055	0.1	0.1	0.1	0.09	0.06			
Mg	24.3050	219	221	248	259	172			
Mn	54.9380	2.8	2.8	4.6	7.1	33			
Mo	95.9400	0.03	0.01	0.01	0.01	0.01			
Na	22.9898	268	214	227	254	119			
Nb	92.9064	0.06	0.01	0.01	0.01	0.02			
Ni	58.7000	16	15	25	25	11			
P	30.9738	1.5	0.1	0.1	0.1	0.04			
Pb	207.2000	0.2	0.01	0.01	0.01	0.01			
S	32.0600	986	833	855	851	541			
Sb	121.7500	0.05	0.01	0.02	0.01	0.01			
Se	78.9600	0.05	0.01	0.02	0.01	0.01			
Si	28.0855	26	25	24	22	6.3			
Sn	118.6900	0.01	0.01	0.01	0.01	0.01			
Sr	87.6200	0.6	0.5	0.5	0.5	0.6			
Te	127.6000	0.09	0.01	0.01	0.01	0.01			
Th	232.0381	0.01	0.01	0.01	0.01	0.01			
Ti	47.9000	0.01	0.01	0.01	0.01	0.01			
U	238.0290	0.03	0.02	0.01	0.01	0.01			
V	50.9415	0.01	0.01	0.01	0.01	0.01			
W	183.8500	0.04	0.01	0.01	0.01	0.01			
Y	88.9059	0.04	0.07	0.07	0.05	0.03			
Zn	65.3800	0.5	0.4	0.5	0.5	0.2			
Zr	91.2200	0.06	0.03	0.03	0.01	0.02			
Chloride	35.453								
Acidity		12.5	19.6						
Alkalinity				30.9	17.7	60.8			
Sulphate	96.06	2954	2496	2562	2550	1621			
T.S.S.									

TABLE A-7. CELL WATER - CHEMISTRY

SAMPLE DATE		07/07/90	07/07/90	07/07/90	07/07/90	07/07/90	07/07/90	07/07/90
ASSAYERS CODE		1873	1875	1869	1870	1874	1871	1872
SAMPLING LOCATION		Seep	Feed Water	Cell 1 Outflow	Cell 1 Outflow	Cell 2 Inflow	Pond A Inflow	Cell 4 Outflow
PROC.CODE	FA		1	3A	3B	4	6	13
Temp.		10.4	11.5	10.8	11.0			
pH		4.79	4.06	3.95	4.27			
Measured mV		197	275	183	230			
Eh		448	525	433	480	258	258	258
Cond. (umhos/cm)								
Cl		62	72	70	76	75	68	60
F		0.6		1.2	2.3	0.6	1.0	
Elements	At.Wght.	mg/L						
Ag	107.8680							
Al	26.9815	0.3	0.5	0.5	0.3	2.6	3.6	4.9
As	74.9216	0.01	0.01	0.01	0.01		0.01	
B	10.8100							
Ba	137.3300	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Be	9.0122							
Bi	208.9804							
C	12.0110							
Ca	40.0800	579	577	533	567	611	582	568
Cd	112.4100	0.1	0.1	0.09	0.1	0.1	0.1	0.08
Ce	140.1200							
Co	58.9332	1.4	1.4	1.4	1.4	1.5	1.6	1.6
Cr	51.9960	0.06	0.08	0.05	0.05	0.06	0.06	0.04
Cu	63.5460	0.1	0.1	0.1	0.1	0.6	1.1	2.7
Fe	55.8470	300	322	274	298	247	236	123
K	39.0983	75	84	75	78	77	76	73
La	138.9055	0.07	0.08	0.06	0.07	0.1	0.1	0.1
Mg	24.3050	182	203	188	197	199	197	191
Mn	54.9380	4.4	4.8	4.7	4.9	5.1	4.9	7.3
Mo	95.9400							
Na	22.9898	100	96	97	100	97	98	101
Nb	92.9064	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Ni	58.7000	33	25	33	35	38	39	41
P	30.9738	0.9	1.1	0.9	1.1	0.9	0.8	0.7
Pb	207.2000	0.3	0.4	0.2	0.3	0.3	0.3	0.3
S	32.0600	950	1007	919	975	1011	983	931
Sb	121.7500		0.01					
Se	78.9600							
Si	28.0855	16	18	15	15	18	17	18
Sn	118.6900							
Sr	87.6200	1.8	2.2	2.1	2.1	2.14	2.1	2.1
Te	127.6000	0.03	0.04	0.02	0.03	0.03	0.03	0.01
Ti	47.9000	0.01	0.02	0.01	0.01	0.01	0.05	0.01
U	238.0290	0.03	0.03	0.03	0.03	0.03	0.03	0.02
V	50.9415	0.01	0.02	0.01	0.01	0.01	0.02	0.01
W	183.8500							
Y	88.9059			0.01		0.03	0.03	0.07
Zn	65.3800	0.5	0.5	0.7	0.6	0.7	0.8	2.4
Zr	91.2200	0.05	0.06	0.04	0.04	0.05	0.04	0.05
Chloride	35.453	62	72	70	76	75	68	60
Sulphate	96.06	2846	3017	2754	2921	3029	2945	2790
Alkalinity		27.5						
Acidity		890	80	770	1290	700	697	567

SAMPLE DATE		18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90
ASSAYERS CODE		1904	1905	1906	1907	1908	1909	1910	1911	1912	1913
SAMPLING LOCATION		Feed Water	Cell 1 Inflow	Cell 1 Outflow	Cell 2 Inflow	Cell 2 Outflow	Pond A Inflow	Pond A Outflow	Cell 3 Inflow	After 1st Curtain	After 2nd Curtain
PROC.CODE	FA	1	2	3	4	5	6	7	8	8A	8B
Temp., C		22	17	23	25	25	26	25	23	22	21
pH, units		4.96	3.71	3.64	2.87	2.85	2.78	2.79	2.80	3.38	3.92
Eh, mV											
Cond.,micromho/cm		2200	3300	3600	3700	3500	3700	3600	3500	3250	3300
Ferric (ppm)											
Ferrous (ppm)											
Elements	At.Wght.	mg/L									
Ag	107.8680										
Al	26.9815	0.4	0.5	0.4	5.2	5.5	5.2	5.1	9.6	10	9.2
As	74.9216	0.7							0.01	0.03	
B	10.8100	0.6	0.5	0.6	0.5	0.5	0.4	0.4	0.3	0.4	0.4
Ba	137.3300	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Be	9.0122						0.01				
Bi	208.9804	0.06	0.02	0.02	0.02	0.05	0.02	0.02	0.02	0.05	0.02
C	12.0110										
Ca	40.0800	449	456	462	482	510	499	485	485	528	526
Cd	112.4100	0.3	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.2	0.09
Ce	140.1200	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.04	0.03
Co	58.9332	1.3	1.2	1.3	1.4	1.6	1.4	1.4	1.3	1.5	1.4
Cr	51.9960	0.1	0.06	0.07	0.06	0.1	0.06	0.06	0.06	0.1	0.06
Cu	63.5460	0.06	0.09	0.08	0.9	0.9	0.9	0.8	1.1	1.2	1.1
Fe	55.8470	276	238	251	164	165	153	148	84	86	89
K	39.0983	92	89.5	88	87	87	83	82	84	86	86
La	138.9055	0.05	0.07	0.07	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mg	24.3050	216	211	214	217	223	215	209	210	219	212
Mn	54.9380	4.4	4.7	4.7	4.7	5.1	4.8	4.7	4.9	5.3	5.3
Mo	95.9400	0.02				0.02				0.02	
Na	22.9898	121	121	122	124	124	120	119	124	122	116
Nb	92.9064	0.04	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.04	0.02
Ni	58.7000	28	30	31	35	36	35	34	32	35	34
P	30.9738	3.3	1.1	1.3	1.1	3.09	0.9	1.1	0.9	2.9	0.8
Pb	207.2000	0.5	0.3	0.3	0.3	0.5	0.2	0.3	0.2	0.34	0.2
S	32.0600	976	949	969	976	1017	982	943	915	986	950
Sb	121.7500										
Se	78.9600										
Si	28.0855	15	14	15	20	21	20	19	22	23	22
Sn	118.6900	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01
Sr	87.6200	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.3	1.3
Te	127.6000	0.07	0.04	0.03	0.03	0.06	0.02	0.03	0.02	0.06	0.02
Ti	47.9000	0.01								0.01	
U	238.0290	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
V	50.9415	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02
W	183.8500	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.03	0.01
Y	88.9059	0.01	0.01	0.01	0.05	0.05	0.05	0.05	0.05	0.06	0.05
Zn	65.3800	0.5	0.7	0.7	0.8	0.8	0.8	0.9	0.8	1.6	1.6
Zr	91.2200										
Chloride	35.453										
Acidity											
Sulphate	96.06	2924	2843	2903	2924	3047	2942	2825	2742	2954	2846
Ammonia											
T.S.S.											

SAMPLE DATE		18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90	18/07/90
ASSAYERS CODE		1914	1915	1916	1917	1918	1919	1920	1921	1922
SAMPLING LOCATION		Cell 3 Outflow	Pond B Inflow	Pond B Outflow	Cell 4 Inflow	After 1st Curtain	After 2nd Curtain	After 3rd Curtain	Cell 4 Outflow	By-pass Channel
PROC.CODE	FA	9	10	11	12	12A	12B	12C	13	End 15
Temp., C		23	22	23	22	23	21	22	22	21
pH, units		3.00	3.00	2.99	3.55	3.32	3.45	3.20	2.82	5.50
Eh, mV										
Cond.,micromho/cm		3700	3700	3600	3600	3600	3400	3700	3800	3500
Ferric (ppm)										
Ferrous (ppm)										
Elements	At.Wght.									
Ag	107.8680									
Al	26.9815	9.32	8.6	8.5	9.3	7.8	6.1	4.3	4.5	0.5
As	74.9216	0.03					0.01		0.03	
B	10.8100	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.6
Ba	137.3300	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Be	9.0122									
Bi	208.9804	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02
C	12.0110									
Ca	40.0800	535	528	510	503	508	505	512	505	473
Cd	112.4100	0.2	0.08	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Ce	140.1200	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.01
Co	58.9332	1.5	1.4	1.4	1.3	1.4	1.3	1.3	1.5	1.4
Cr	51.9960	0.1	0.06	0.06	0.06	0.06	0.06	0.06	0.1	0.07
Cu	63.5460	1.1	0.9	0.9	0.8	0.6	0.4	0.4	0.6	0.1
Fe	55.8470	108	91	88	72	72	80	73	85	285
K	39.0983	103	103	96	104	106	118	127	110	82
La	138.9055	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.07
Mg	24.3050	220	218	213	213	209	212	211	202	213
Mn	54.9380	5.6	5.7	5.5	5.7	5.9	6.6	8.1	8.2	4.7
Mo	95.9400	0.02							0.02	
Na	22.9898	129	129	123	126	123	127	126	115	108
Nb	92.9064	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02
Ni	58.7000	35	35	34	34	34	33	33	32	31
P	30.9738	2.9	0.9	0.9	0.9	0.9	0.9	0.9	3.1	1.2
Pb	207.2000	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.3
S	32.0600	993	971	939	920	921	939	959	937	999
Sb	121.7500									
Se	78.9600									
Si	28.0855	32	22	21	22	21	20	19	18	17
Sn	118.6900	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Sr	87.6200	1.3	1.3	1.3	1.2	1.3	1.3	1.3	1.2	1.3
Te	127.6000	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.03
Ti	47.9000	0.01								
U	238.0290	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
V	50.9415	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
W	183.8500	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
Y	88.9059	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01
Zn	65.3800	2.1	1.8	1.8	1.7	1.8	1.8	2.1	2.2	0.5
Zr	91.2200									
Chloride	35.453									
Acidity										
Sulphate	96.06	2975	2909	2813	2757	2760	2813	2873	2807	2993
Ammonia										
T.S.S.										

SAMPLE DATE		08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90
ASSAYERS CODE		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
SAMPLING LOCATION		Seep	Feed Water	Cell 1 Inflow	Cell 1	Cell 1 Outflow	Cell 2 Inflow	Cell 2	Cell 2 Outflow	Pond A Inflow	Pond A Outflow
PROC.CODE	FA		1	2	3A	3B	4A	4B	5	6	7
Temp.		14.0	15.5	18.2	18.0	18.0	18.5	19.2	18.5	19.5	19.5
pH		6.40	6.20	3.89	3.91	4.02	2.94	2.95	2.95	2.93	2.92
Measured mV		-48	-21	99	109	124	212	212	211	215	277
Eh		200	226	344	355	370	457	457	456	460	522
Cond. (umhos/cm)		3000	3220	3270	3270	3270	3670	3700	3700	3720	3720
Ferric (ppm)		)60	)60	)60	)60	)60	)60	)60	)60	)60	)60
Ferrous (ppm)							<5	<5	<5	<5	<5
Elements	At.Wght.	mg/L									
Ag	107.8680				0.01	0.01	0.01				
Al	26.9815	0.3	0.2	1.3	1.3	10	10	10	14	14	14
As	74.9216					0.01	0.01	0.01	0.01	0.01	0.01
B	10.8100	0.9	1.1	0.9	0.9	0.9	0.6	0.6	0.6	0.5	0.6
Ba	137.3300	0.03	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01
Be	9.0122										
Bi	208.9804	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C	12.0110										
Ca	40.0800	529	510	522	542	559	584	574	538	543	574
Cd	112.4100	0.08	0.09	0.09	0.1	0.1	0.1	0.1	0.09	0.1	0.1
Ce	140.1200	0.02	0.02	0.03	0.04	0.04	0.07	0.06	0.06	0.06	0.07
Co	58.9332	1.1	1.3	1.4	1.5	1.5	1.9	1.8	1.7	2.2	2.3
Cr	51.9960	0.07	0.08	0.09	0.1	0.1	0.1	0.09	0.08	0.08	0.09
Cu	63.5460	0.07	0.04	0.5	0.5	0.5	2.2	2.2	2.2	5.8	6.1
Fe	55.8470	302	332	278	297	308	160	159	147	127	134
K	39.0983	88	89	80	83	86	74	74	71	69	71
La	138.9055	0.07	0.05	0.1	0.1	0.1	0.3	0.2	0.2	0.3	0.3
Mg	24.3050	194	212	208	212	218	219	219	211	216	222
Mn	54.9380	4.2	4.8	5.3	5.3	5.5	5.8	5.8	5.5	5.6	5.8
Mo	95.9400										
Na	22.9898	127	117	108	109	113	108	109	107	109	110
Nb	92.9064	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Ni	58.7000	29	32	37	38	39	50	49	46	61	65
P	30.9738	1.2	1.2	1.2	1.4	1.4	1.2	1.1	0.9	1.1	1.1
Pb	207.2000	0.3	0.3	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.3
S	32.0600	1043	1093	1088	1136	1161	1164	1163	1104	1134	1180
Sb	121.7500										
Se	78.9600										
Si	28.0855	17	16	17	17	18	29	28	27	28	29
Sn	118.6900										
Sr	87.6200	2.2	2.3	2.1	2.2	2.2	2.3	2.3	2.2	2.2	2.2
Te	127.6000	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
Ti	47.9000	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
U	238.0290	0.04	0.04	0.04	0.04						
V	50.9415	0.04	0.04	0.06	0.07	0.07	0.08	0.07	0.06	0.06	0.07
W	183.8500	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Y	88.9059	0.01	0.01	0.03	0.04	0.03	0.1	0.1	0.1	0.1	0.1
Zn	65.3800	0.5	0.5	0.9	1.1	1.1	1.3	1.2	1.3	1.7	1.7
Zr	91.2200	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.07
Chloride	35.453										
Sulphate	96.06	3125	3275	3260	3404	3479	3488	3485	3308	3398	3536
Alkalinity		91	54								
Acidity		800	855	745	765	758	742	745	755	764	778

SAMPLE DATE		08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90
ASSAYERS CODE		2027	2028	2029	2030	2031	2032	2033
SAMPLING LOCATION		Cell 3 Inflow	Cell 3 Outflow	Pond B Inflow	Pond B Outflow	Cell 4 Inflow	Cell 4 Outflow	System Outflow
PROC.CODE	FA	8	9	10	11	12	13	14
Temp.		19.5	19.5	19.5	19.5	19.5	19.8	19.0
pH		2.99	3.02	3.02	2.96	3.02	3.05	3.03
Measured mV		230	238	240	222	253	262	304
Eh		475	483	485	467	498	506	549
Cond. (umhos/cm)		3700	3740	3820	3780	3700	3720	3680
Ferric (ppm)		<5		<5	<5	<5		
Ferrous (ppm)		<5	<5	<5	<5	<5	<5	<5
Elements	At.Wght.							
Ag	107.8680	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al	26.9815	19	19	19	18	14	14	13
As	74.9216	0.01	0.01	0.01	0.01	0.01	0.01	0.01
B	10.8100	0.4	0.4	0.5	0.4	0.5	0.4	0.4
Ba	137.3300	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Be	9.0122							
Bi	208.9804	0.03	0.03	0.04	0.03	0.03	0.02	0.025
C	12.0110							
Ca	40.0800	610	616	612	595	594	629	914
Cd	112.4100	0.1	0.1	0.1	0.1	0.09	0.09	0.09
Ce	140.1200	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Co	58.9332	2.1	2.1	2.4	2.3	1.6	1.6	1.5
Cr	51.9960	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cu	63.5460	4.2	4.1	5.4	5.3	2.1	1.7	1.6
Fe	55.8470	51	53	60	59	41	50	47
K	39.0983	76	78	77	76	89	94	93
La	138.9055	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Mg	24.3050	221	225	223	218	207	218	211
Mn	54.9380	7.1	7.3	7.8	7.6	9.4	10	10
Mo	95.9400							
Na	22.9898	115	119	116	113	113	121	117.6
Nb	92.9064	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Ni	58.7000	57	57	68	66	43	43	41
P	30.9738	1.1	0.9	1.1	1.1	0.9	1.1	0.9
Pb	207.2000	0.3	0.4	0.3	0.4	0.3	0.3	0.3
S	32.0600	1143	1146	1158	1141	1085	1128	1098
Sb	121.7500							
Se	78.9600							
Si	28.0855	33	33	32	31	30	31	30
Sn	118.6900							
Sr	87.6200	2.4	2.5	2.4	2.3	2.4	2.6	2.5
Te	127.6000	0.03	0.03	0.04	0.03	0.03	0.03	0.03
Ti	47.9000	0.03	0.02	0.03	0.02	0.02	0.02	0.02
U	238.0290						0.03	0.03
V	50.9415	0.08	0.08	0.09	0.08	0.07	0.08	0.07
W	183.8500	0.03	0.03	0.03	0.03	0.03	0.03	0.02
Y	88.9059	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Zn	65.3800	5.7	6.3	5.8	5.6	5.4	5.3	4.9
Zr	91.2200	0.07	0.07	0.07	0.07	0.07	0.03	0.03
Chloride	35.453							
Sulphate	96.06	3425	3434	3470	3419	3251	3380	3290
Alkalinity								
Acidity		598	560	595	630	520	505	505

TABLE A-10. CELL WATER - CHEMISTRY

SAMPLE DATE	23/08/90	23/08/90	23/08/90	23/08/90	23/08/90
ASSAYERS CODE	2066	2068	2067	2069	2070
SAMPLING LOCATION	Seep ?????	Pond B ?????	#3 ?????	#4 ?????	#5 ARUM BOT
PROC.CODE FA		6	10	14	????
Temperature, C	20.1	27.9	26.3	25	19
pH, units	5.95	2.8	2.79	2.9	6.28
Measured mV	-85	444	450	423	-180
Eh, mV	159	683	690	664	65
Cond.,micromho/cm					
Ferric (ppm)		30	20	5	
Ferrous (ppm)			45	20	
Elements At.Wght.	mg/L				
Ag 107.8680					
Al 26.9815	0.1	7.1	14	19	0.1
As 74.9216		0.01		0.01	0.01
B 10.8100	0.7	0.5	0.4	0.3	0.8
Ba 137.3300	0.03	0.01	0.02	0.02	0.04
Be 9.0122					
Bi 208.9804	0.02	0.02	0.02	0.02	0.02
C 12.0110					
Ca 40.0800	512	532	536	587	602
Cd 112.4100	0.08	0.09	0.07	0.08	0.07
Ce 140.1200	0.02	0.04	0.06	0.07	0.02
Co 58.9332	1.1	1.4	1.5	1.6	0.4
Cr 51.9960	0.07	0.07	0.07	0.07	0.09
Cu 63.5460	0.04	0.7	1.9	1.2	0.02
Fe 55.8470	285	184	78	48	402
K 39.0983	87	76	70	67	52
La 138.9055	0.06	0.2	0.3	0.3	0.04
Mg 24.3050	176	216	222	224	187
Mn 54.9380	3.9	5.6	7.2	11	22
Mo 95.9400	0.06		0.06		
Na 22.9898	131	119	127	131	134
Nb 92.9064	0.02	0.02	0.02	0.03	0.04
Ni 58.7000	25	36	40	46	8.1
P 30.9738	1.1	1.1	0.7	0.7	1.4
Pb 207.2000	0.2	0.2	0.2	0.2	0.2
S 32.0600	948	1055	1046	1042	903
Sb 121.7500	0.01	0.08	0.01	0.07	0.07
Se 78.9600	0.04	0.03	0.02	0.02	0.06
Si 28.0855	15	23	29	32	13
Sn 118.6900	0.01	0.01	0.01	0.01	0.02
Sr 87.6200	2.2	2.4	2.6	2.8	3.3
Te 127.6000	0.03	0.02	0.02	0.02	0.03
Ti 47.9000	0.01	0.01	0.01	0.01	0.01
U 238.0290	0.04	0.03	0.03	0.03	0.04
V 50.9415	0.03	0.04	0.04	0.04	0.03
W 183.8500	0.01	0.01	0.02	0.02	0.01
Y 88.9059	0.01	0.09	0.1	0.1	0.01
Zn 65.3800	0.4	0.9	4.3	4.9	0.5
Zr 91.2200	0.05	0.05	0.05	0.05	0.06
Chloride 35.453					
Sulphate 96.06	2840	3161	3134	3122	2706
Alkalinity	120				600
Acidity	710	760	660	605	880

TABLE B-1. PIEZOMETERS WATERS - CHEMISTRY

SAMPLE DATE		10/05/90	10/05/90	10/05/90	10/05/90	10/05/90	10/05/90
ASSAYERS CODE		1704	1705	1706	1707	1708	1709
SAMPLING LOCATION		P1	P2	P3	P4	P6	P7
Processing Code		FA	FA	FA	FA	FA	FA
Temperature, C		17.0	17.0	17.0	16.5	17.8	18.2
pH, units		7.00	6.78	7.04	6.63	7.22	5.21
Measured millivolts							
Eh, millivolts							
Conductivity, micromhos/cm		2680	2720	2970	2800	2700	2530
Ferrous							
Ferric							
ELEMENTS	AT.WGHT	mg/L					
Ag	107.8680						
Al	26.9815		0.02			0.08	0.1
As	74.9216						
B	10.8100	0.05	0.09	0.1	0.1	0.08	0.1
Ba	137.3300	0.1	0.1	0.1	0.07	0.06	0.04
Bi	208.9804						
Ca	40.0800	592	771	746	753	694	581
Cd	112.4100	0.07	0.06	0.06	0.07	0.07	0.1
Ce	140.1200	0.02	0.03	0.02	0.03		
Co	58.9332	0.1	0.4	0.2	0.2	0.1	1.1
Cr	51.9960	0.1	0.1	0.1	0.1	0.1	0.1
Cu	63.5460	0.08					0.5
Fe	55.8470					0.04	124
K	39.0983	8.7	8.6	55	59	12	59
La	138.9055	0.05	0.06	0.05	0.05	0.05	0.1
Mg	24.3050	273	257	283	239	326	265
Mn	54.9380	2.2	44	28	21	4.9	6.1
Na	22.9898	180	163	201	192	168	143
Nb	92.9064						
Ni	58.7000	1.9	5.5	3.7	1.9	1.7	25
P	30.9738	0.5	0.6	0.8	0.9	0.8	0.9
Pb	207.2000	0.04	0.1	0.1	0.06	0.1	0.1
S	32.0600	805	951	966	950	922	1020
Si	28.0855	3.4	11.4	9.4	7.9	8.1	8.2
Sr	87.6200	3.2	4.9	4.6	4.1	1.7	2.9
Te	127.6000						
Th	232.0381	0.01	0.01	0.01	0.01	0.01	0.01
Ti	47.9000	0.01	0.01	0.01	0.01	0.01	0.01
U	238.0290	0.01	0.01	0.01	0.01	0.01	0.01
V	50.9415	0.03	0.03	0.03	0.02	0.01	0.02
W	183.8500						
Y	88.9059	0.01	0.01	0.01	0.01		0.04
Zn	65.3800	2.1	0.9	0.3	0.1	0.08	0.7
Zr	91.2200	0.04	0.05	0.05	0.05	0.05	0.06
Alkalinity							
Acidity							
Sulfate	96.0600	2412	2849	2894	2846	2763	3056
SULFUR, millimoles/2		12.55	14.83	15.07	14.82	14.38	15.91
METALS. millimoles		0.11	0.91	0.58	0.42	0.12	2.78
METAL LOST, %		99.2%	93.9%	96.2%	97.2%	99.2%	82.5%
SUM of CATIONS		60.12	66.96	70.67	67.11	69.08	65.21
SUM of ANIONS		50.22	59.33	60.26	59.26	57.52	63.63
% ERROR		9%	6%	8%	6%	9%	1%

SAMPLE DATE		07/07/90	07/07/90	07/07/90	07/07/90	07/07/90	07/07/90	07/07/90
ASSAYERS CODE		1851	1852	1853	1854	1855	1856	1857
SAMPLING LOCATION		P1	P2	P3	P4	P5	P6	P7
Processing Code		FA	FA	FA	FA	FA	FA	FA
Temperature, C		20	21	23	22	22.5	19	19
pH, units		6.54	6.37	6.34	6.38	6.46	6.81	5.11
Measured millivolts		-10	130	107	167	-41	167	142
Eh, millivolts		234	374	349	410	202	412	387
Conductivity, micromhos/cm		2760	2805	3080	2870	3120	2670	2810
Cl		81	84	78	65	83	74	80
F		2.5	1.2	1.9	0.6	4.1	0.9	
ELEMENTS	AT.WGHT	mg/L						
Ag	107.8680			0.01		0.01		0.01
Al	26.9815	0.12	0.2	0.4	0.3	0.4	0.3	0.4
As	74.9216							
B	10.8100							
Ba	137.3300	0.04	0.04	0.04	0.04	0.04	0.03	0.02
Bi	208.9804							
Ca	40.0800	592	757	840	834	848	743	725
Cd	112.4100			0.03	0.03	0.05	0.02	0.08
Ce	140.1200	0.01	0.02	0.03	0.03			
Co	58.9332	0.05	0.2	0.1	0.1	0.3	0.03	0.9
Cr	51.9960	0.02	0.06	0.09	0.07	0.1	0.06	0.08
Cu	63.5460	0.01	0.01	0.03	0.03	0.04	0.02	0.2
Fe	55.8470	1.6	0.1	2.1	0.5	80	0.4	174
K	39.0983	6.4	9.6	77	68	68	6.6	67
La	138.9055	0.03	0.05	0.08	0.1	0.09	0.06	0.1
Mg	24.3050	227	172	181	153	159	230	190
Mn	54.9380	1.5	41	29	19	19	2.7	6.2
Na	22.9898	198	140	138	146	178	125	106
Nb	92.9064	0.01	0.03	0.04	0.03	0.04	0.02	0.03
Ni	58.7000	0.3	2.1	0.8	0.3	10	0.1	20
P	30.9738	0.5	0.7	0.6	0.5	0.7	0.6	0.8
Pb	207.2000	0.1	0.1	0.2	0.2	0.3	0.2	0.3
S	32.0600	741	782	818	826	868	778	982
Si	28.0855	4.7	15	12	10	14	11	13
Sr	87.6200	2.5	3.9	3.1	2.8	3.3	0.9	2.3
Te	127.6000					0.03	0.02	0.03
Th	232.0381			0.01		0.01	0.01	0.01
Ti	47.9000	0.01	0.01	0.02	0.02	0.02	0.01	0.02
U	238.0290	0.02	0.02	0.03	0.03	0.03	0.02	0.03
V	50.9415		0.01	0.02	0.02	0.03	0.01	0.02
W	183.8500							
Y	88.9059				0.01			0.03
Zn	65.3800	0.06	0.06	0.04	0.03	0.2	0.02	0.6
Zr	91.2200	0.02	0.04	0.06	0.05	0.07	0.05	0.06
Alkalinity		440	420	525	260	365	392	
Acidity		200	190	80	155	345	120	450
Sulfate	96.06	2220	2343	2451	2475	2601	2331	2942
SULFUR, millimoles/2		11.56	12.20	12.76	12.88	13.54	12.13	15.32
METALS, millimoles		0.06	0.78	0.58	0.36	1.95	0.06	3.58
METALS LOST		99.5%	93.6%	95.5%	97.2%	85.6%	99.5%	76.6%
SUM of CATIONS		57.21	59.93	66.05	63.09	70.30	61.75	68.50
SUM of ANIONS		55.02	57.18	61.53	56.73	61.45	56.37	61.26
% ERROR		1.95%	2.35%	3.55%	5.31%	6.72%	4.56%	5.58%

TABLE B-3. PIEZOMETER WATERS - CHEMISTRY

SAMPLE DATE		08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90
ASSAYERS CODE		2034	2035	2036	2037	2038	2039	2040	2041	2042
SAMPLING LOCATION		P1	P2	P3	P4	P5	P6	P7	P8	P9
Processing Code		FA	FA	FA	FA	FA	FA	FA	FA	FA
Temperature, C		24.0	22.2	21.0	20.2	22.0	19.8	21.8	20.2	19.8
pH, units		6.50	6.41	6.56	6.60	6.40	6.81	5.39	6.95	6.86
Measured millivolts		139	143	2	77	-83	102	81	-11	97
Eh, millivolts		381	386	246	321	160	346	324	233	341
Conductivity, micromhos/cm		3490	3300	3710	3350	3900	3100	3300	2250	1900
Ferrous							>60	>60		
Ferric										
ELEMENTS	AT.WGHT	mg/L								
Ag	107.8680	0.01	0.01	0.01						
Al	26.9815	0.5	0.4	0.4	0.4	0.3	0.1	0.4	0.1	0.1
As	74.9216	0.01	0.01	0.01	0.1	0.01	0.01	0.01		
B	10.8100	0.2	0.3	0.3	0.3	0.5	0.1	0.5	0.1	0.1
Ba	137.3300	0.05	0.05	0.05	0.04	0.05	0.04	0.02	0.1	0.08
Bi	208.9804	0.01	0.02	0.02	0.01	0.02	0.01	0.03	0.01	0.01
Ca	40.0800	642	773	689	638	631	511	509	286	314
Cd	112.4100	0.03	0.03	0.03	0.01	0.05	0.01	0.2	0.01	0.01
Ce	140.1200	0.03	0.04	0.04	0.03	0.02	0.02	0.06	0.01	0.01
Co	58.9332	0.1	0.3	0.09	0.1	0.5	0.03	3.2	0.1	0.04
Cr	51.9960	0.09	0.1	0.1	0.07	0.07	0.05	0.07	0.04	0.04
Cu	63.5460	0.07	0.05	0.05	0.05	0.03	0.02	1.4	0.07	0.1
Fe	55.8470	1.1	0.3	1.4	0.6	89	0.2	147	1.3	0.1
K	39.0983	11	13	81	70	72	4.3	64	2.7	3.7
La	138.9055	0.08	0.1	0.09	0.09	0.06	0.04	0.3	0.03	0.03
Mg	24.3050	212	168	163	134	156	205	173	165	141
Mn	54.9380	1.9	39	24	15	16	1.5	6.4	5.2	1.8
Na	22.9898	183	137	145	150	189	117	104	33	37
Nb	92.9064	0.03	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01
Ni	58.7000	1.1	2.2	0.6	0.5	15	0.1	91	1.1	0.2
P	30.9738	0.7	0.7	0.8	0.5	0.7	0.5	0.9	0.4	0.4
Pb	207.2000	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.07	0.1
S	32.0600	818	850	799	774	860	682	965	438	437
Si	28.0855	6.5	18	12	11	14	11	17	7.2	5.1
Sr	87.6200	2.5	4.1	3.2	2.8	3.8	0.6	2.1	1.1	1.4
Te	127.6000	0.02	0.02	0.02	0.01	0.02	0.01	0.02		0.01
Th	232.0381	0.1	0.09	0.08	0.06	0.08	0.08	0.09	0.06	0.06
Ti	47.9000	0.02	0.03	0.02	0.03	0.02	0.01	0.01	0.01	0.01
U	238.0290	0.03	0.04	0.03						
V	50.9415	0.06	0.08	0.07	0.04	0.05	0.03	0.06	0.02	0.03
W	183.8500	0.01	0.02	0.01	0.01	0.01	0.01	0.02		
Y	88.9059	0.01	0.02	0.01	0.01	0.01	0.01	0.07		
Zn	65.3800	0.1	0.06	0.03	0.04	0.2	0.01	3.2	0.04	0.01
Zr	91.2200	0.03	0.07	0.07	0.05	0.05	0.04	0.05	0.02	0.03
Alkalinity		420	366	500	270	390	350	24	440	176
Acidity								670		
Sulfate	96.06	2451	2547	2394	2319	2577	2043	2891	1312	1309
SULFUR, millimoles/2		12.76	13.26	12.46	12.07	13.41	10.64	15.05	6.83	6.82
METALS, millimoles		0.08	0.75	0.47	0.29	2.14	0.03	4.37	0.14	0.04
METALS LOST		99.4%	94.3%	96.2%	97.6%	84.0%	99.7%	71.0%	98.0%	99.4%
SUM of CATIONS		57.95	60.31	57.22	51.84	60.37	47.65	57.32	29.68	29.09
SUM of ANIONS		59.43	60.34	59.84	53.68	61.45	49.54	60.68	36.12	30.78
% ERROR		-1.26%	-0.03%	-2.24%	-1.74%	-0.88%	-1.95%	-2.84%	-9.79%	-2.82%

TABLE C-1. ARUMATOR WATERS - CHEMISTRY

SAMPLE DATE		06/06/90	06/06/90	06/06/90	06/06/90	06/06/90	06/06/90	06/06/90	06/06/90	06/06/90
ASSAYERS CODE		1730	1731	1732	1733	1734	1735	1736	1737	1738
SAMPLING LOCATION		A1-TOP	A1-MID	A1-BOT	A2-TOP	A2-MID	A2-BOT	A3-TOP	A3-MID	A3-BOT
Processing Code		FA	FA	FA	FA	FA	FA	FA	FA	FA
Temperature, C		17.0	17.5	18.0	22.0	20.0	20.0	20.0	20.0	20.0
pH, units		5.75	5.14	5.77	5.18	5.09	5.27	4.45	4.76	4.75
Measured millivolts										
Eh, millivolts										
Cond., micromho/cm		2320	5635	6042	2650	4950	4070	4510	4840	4620
Ferrous										
Ferric										
ELEMENTS	AT.WGHT	mg/L								
Ag	107.8680									
Al	26.9815	0.7	1.9	1.3	0.9	1.7	1.7	0.4	0.2	0.3
As	74.9216									
B	10.8100		0.4	0.4		0.4	0.4	0.06	0.06	0.03
Ba	137.3300	0.05	0.1	0.1	0.09	0.2	0.1	0.1	0.09	0.08
Bi	208.9804		0.04	0.04		0.03	0.04	0.03	0.03	0.03
Ca	40.0800	281	616	646	347	653	708	541	549	507
Cd	112.4100		0.02	0.02		0.01	0.01	0.02	0.02	0.02
Ce	140.1200		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Co	58.9332	0.03	3.4	3.7	0.5	2.8	3.1	4.5	4.7	4.5
Cr	51.9960	0.02	0.1	0.2	0.1	0.2	0.2	0.06	0.06	0.05
Cu	63.5460		0.02	0.01	0.01	0.03	0.2	0.03	0.02	0.3
Fe	55.8470	17	371	440	99	369	390	125	121	103
K	39.0983	78	307	339	106	329	358	215	239	229
La	138.9055	0.01	0.04	0.03	0.03	0.04	0.04	0.07	0.04	0.05
Mg	24.3050	115	322	380	146	298	321	279	296	291
Mn	54.9380	3.7	15	17	4.8	12	14	23	24	23
Na	22.9898	100	271	309	124	233	250	182	202	212
Nb	92.9064		0.03	0.04	0.01	0.03	0.03	0.03	0.03	0.02
Ni	58.7000	1.7	97	96	12	77	80	147	152	149
P	30.9738	2.6	13	6.6	4.2	18	18	10	8.3	4.7
Pb	207.2000		0.4	0.5	0.07	0.4	0.5	0.3	0.3	0.3
S	32.0600	403	1434	1751	628	1438	1673	1309	1522	1152
Si	28.0855	7.9	18	19	10	15	17	15	15	14
Sr	87.6200	1.5	3.5	3.6	1.9	3.5	3.7	3.2	3.3	3.4
Te	127.6000		0.03	0.04		0.03	0.04	0.02	0.01	0.01
Th	232.0381		0.01	0.01		0.01	0.01	0.01	0.01	0.01
Ti	47.9000		0.01			0.01	0.01			
U	238.0290	0.01	0.03	0.03	0.01	0.03	0.03	0.02	0.02	0.02
V	50.9415	0.01	0.07	0.07	0.01	0.06	0.06	0.06	0.06	0.07
W	183.8500		0.02	0.02		0.01	0.02	0.02	0.01	0.01
Y	88.9059									
Zn	65.3800		1.5	0.5	0.1	0.05	1.6	4.2	4.3	4.2
Zr	91.2200	0.01	0.06	0.07	0.01	0.05	0.06	0.05	0.05	0.04
Alkalinity		130	270	370	100	310	290		55	30
Acidity		400	1800	2650	550	2250	1900	1550	1350	1100
Sulfate	96.06	1207	4297	5246	1882	4309	5013	3922	4560	3452
SULFUR, millimoles/2		6.29	22.36	27.31	9.79	22.43	26.09	20.41	23.74	17.97
METALS, millimoles		0.40	8.59	9.83	2.07	8.14	8.63	5.23	5.26	4.87
METALS LOST, %		93.6%	61.6%	64.0%	78.9%	63.7%	66.9%	74.4%	77.8%	72.9%
SUM of CATIONS		30.97	100.90	113.37	43.40	98.72	106.20	76.29	79.57	76.14
SUM of ANIONS		27.74	94.86	116.63	41.18	95.91	110.17	81.66	96.05	72.47
% ERROR		6%	3%	-1%	3%	1%	-2%	-3%	-9%	2%

SAMPLE DATE		07/07/90	07/07/90	07/07/90	07/07/90	07/07/90
ASSAYERS CODE		1858	1859	1862	1861	1860
SAMPLING LOCATION		A1-HOMO	A2-HOMO	A3-TOP	A3-MID	A3-BOT
Processing Code		FA	FA	FA	FA	FA
Temperature, C		22.0	24.0	20.0	20.0	21.0
pH, units		6.01	5.61	4.44	4.49	4.72
Measured millivolts		-335	-312	-196	-157	-217
Eh, millivolts		-92	-70	48	87	27
Conduct., micromho/cm		1990	2600	3760	4080	3940
Ferrous						
Ferric						
ELEMENTS	AT.WGHT	mg/L				
Ag	107.8680	0.01	0.01			0.01
Al	26.9815	0.9	1.4	0.9	1.5	1.1
As	74.9216					
B	10.8100					
Ba	137.3300	0.05	0.09	0.1	0.1	0.1
Bi	208.9804					
Ca	40.0800	506	672	737	813	824
Cd	112.4100	0.03	0.04	0.2	0.2	0.2
Ce	140.1200					
Co	58.9332	0.02	0.07	5.1	5.8	5.1
Cr	51.9960	0.1	0.2	0.1	0.1	0.1
Cu	63.5460	0.03	0.04	0.03	0.04	0.08
Fe	55.8470	2.5	9.9	206	223	274
K	39.0983	78	110	176	202	181
La	138.9055		0.07	0.1	0.1	0.2
Mg	24.3050	126	159	247	282	256
Mn	54.9380	5.6	7.8	28	31	30
Na	22.9898	87	105	139	159	137
Nb	92.9064	0.02	0.03	0.04	0.04	0.05
Ni	58.7000	0.3	1.1	157	181	160
P	30.9738	2.2	5.3	14	14	18
Pb	207.2000	0.2	0.3	0.5	0.6	0.7
S	32.0600	559	532	990	1135	1061
Si	28.0855	13	17	20	20	25
Sr	87.6200	1.5	1.9	2.8	3.1	2.9
Te	127.6000	0.02	0.03	0.03	0.04	0.05
Th	232.0381		0.01	0.01	0.01	0.01
Ti	47.9000	0.02	0.02	0.03	0.07	0.02
U	238.0290	0.02	0.03	0.03	0.03	0.04
V	50.9415	0.02	0.03	0.05	0.05	0.06
W	183.8500					
Y	88.9059		0.01	0.02	0.03	0.03
Zn	65.3800	0.04	0.04	2.8	4.1	2.3
Zr	91.2200	0.05	0.07	0.06	0.07	0.08
Alkalinity	5 mL/0.02	433	560			247
Acidity	5 mL/0.01	267	350	1346	1430	1317
Sulfate	96.06	1675	1594	2966	3401	3179
SULFUR, millimoles/2		8.72	8.30	15.44	17.70	16.55
METALS, millimoles		0.15	0.34	6.92	7.70	8.21
METALS LOST, %		98.2%	95.9%	55.2%	56.5%	50.4%
SUM of CATIONS		41.78	54.90	85.41	95.53	94.35
SUM of ANIONS		43.53	44.39	61.76	70.80	71.13
% ERROR		-2%	11%	16%	15%	14%

SAMPLE DATE		08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90	08/08/90
ASSAYERS CODE		2043	2044	2045	2046	2047	2048	2049	2050	2051
SAMPLING LOCATION		A1-TOP	A1-MID	A1-BOT	A2-TOP	A2-MID	A2-BOT	A3-TOP	A3-MID	A3-BOT
Processing Code		FA	FA	FA	FA	FA	FA	FA	FA	FA
Temperature, C		21.5	21.0	21.0	22.2	23.0	23.8	20.5	20.0	21.0
pH, units		6.65	5.87	6.59	6.74	6.72	6.30	4.93	5.02	5.27
Measured millivolts		-352	-275	-329	-314	-338	-276	-104	-148	-132
Eh, millivolts		-109	-31	-85	-71	-96	-34	140	96	112
Conduct., micromho/cm		2620	4520	5900	3550	3540	3900	4410	4450	5000
Ferrous			>60				10	>60	>60	>60
Ferric										
ELEMENTS	AT.WGHT	mg/L								
Ag	107.8680								0.01	
Al	26.9815	1.5	1.6	1.6	0.7	2.8	2.5	0.6	0.7	0.6
As	74.9216	0.01	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.02
B	10.8100	0.4	0.4	0.4	0.2	0.6	0.6	0.7	0.7	0.2
Ba	137.3300	0.1	0.1	0.1	0.06	0.2	0.2	0.1	0.1	0.1
Bi	208.9804	0.02	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.06
Ca	40.0800	635	634	646	427	797	1050	650	719	710
Cd	112.4100	0.02	0.02	0.02	0.02	0.03	0.02	0.1	0.1	0.2
Ce	140.1200	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03
Co	58.9332	0.05	0.04	0.03	0.02	0.04	0.04	3.1	4.1	5.1
Cr	51.9960	0.2	0.2	0.2	0.1	0.3	0.5	0.1	0.1	0.1
Cu	63.5460	0.03	0.04	0.03	0.02	0.03	0.02	0.04	0.04	0.05
Fe	55.8470	2.77	1.1	18	0.6	56	1.8	201	205	484
K	39.0983	200	199	213	96	259	353	185	215	216
La	138.9055	0.06	0.06	0.06	0.04	0.07	0.05	0.1	0.1	0.08
Mg	24.3050	207	206	217	133	304	422	239	275	272
Mn	54.9380	10	9.9	10	5.6	17	28	25	29	31
Na	22.9898	157	156	162	108	234	317	146	169	169
Nb	92.9064	0.03	0.03	0.03	0.02	0.03	0.04	0.04	0.04	0.05
Ni	58.7000	1.1	0.3	0.3	0.2	0.5	0.7	94	106	149
P	30.9738	6.4	6.5	8.2	2.6	15	23	18	14	18
Pb	207.2000	0.2	0.1	0.2	0.1	0.2	0.3	0.4	0.4	0.6
S	32.0600	484	570	507	2731	813	650	1041	1181	1207
Si	28.0855	19	19	19	14	27	31	24	23	24
Sr	87.6200	2.5	2.5	2.6	1.8	3.5	4.7	3.1	3.3	3.3
Te	127.6000	0.02	0.02	0.02	0.01	0.02	0.02	0.03	0.04	0.06
Th	232.0381	0.09	0.09	0.1	0.06	0.1	0.1	0.1	0.1	0.1
Ti	47.9000	0.02	0.02	0.02	0.01	0.03	0.02	0.02	0.02	0.02
U	238.0290	0.03	0.03	0.03	0.02	0.03	0.03	0.04	0.04	0.05
V	50.9415	0.06	0.06	0.06	0.04	0.08	0.09	0.08	0.08	0.09
W	183.8500	0.01	0.01	0.01	0.01	0.01	0.025	0.02	0.02	0.02
Y	88.9059	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.03	0.03
Zn	65.3800	0.01	0.01	0.02	0.02	0.02	0.02	0.9	1.3	0.9
Zr	91.2200	0.05	0.05	0.05	0.03	0.05	0.04	0.06	0.07	0.08
Alkalinity	5 mL/0.02	948	1750	3596	1256	1288	1440	300	336	760
Acidity	5 mL/0.01	400	1559	1318			660	1680	1400	2140
Sulfate	96.06	1450	1708	1519	8183	2436	1948	3119	3539	3616
SULFUR, millimoles/2		7.55	8.89	7.91	42.59	12.68	10.14	16.24	18.42	18.82
METALS, millimoles		0.25	0.21	0.51	0.12	1.32	0.55	5.67	6.02	11.78
METALS LOST, %		96.7%	97.7%	93.5%	99.7%	89.6%	94.5%	65.1%	67.3%	37.4%
SUM of CATIONS		61.27	60.95	63.99	39.69	85.32	111.19	78.30	87.29	103.17
SUM of ANIONS		49.15	70.55	103.54	195.48	76.47	69.34	70.94	80.39	90.49
% ERROR		11%	-7%	-24%	-66%	5%	23%	5%	4%	7%

MAKELA SEEPAGE WATER - CHANGES with TIME

Experiment started on August 16, 1990.
Sample volume 10 mL, Titrant = 0.01N NaOH.

TIME, hrs	0		7		24		72		216	
pH	mL NaOH	pH	mL NaOH	pH	mL NaOH	pH	mL NaOH	pH	mL NaOH
6.00	0.0	5.20	0.0	4.20	0.0	3.70	0.0	2.50	0.0
6.18	1.0	5.70	1.0	5.00	2.0	4.10	0.5	2.60	1.0
6.25	2.0	5.90	2.0	5.30	3.2	4.80	1.0	3.00	2.5
6.45	5.0	6.08	4.0	5.50	4.0	5.10	1.4	3.00	3.0
6.60	7.0	6.15	5.0	5.60	5.0	5.30	2.0	3.00	4.0
6.62	9.0	6.30	7.0	5.75	7.0	5.45	3.0	3.30	5.0
6.85	10.0	6.42	9.0	5.90	9.0	5.55	4.0	3.40	6.0
6.95	12.0	6.50	10.0	6.10	11.0	5.80	6.0	3.50	7.0
7.10	13.0	6.90	12.0	6.40	12.0	5.90	8.0	3.70	8.0
7.38	14.0	7.45	13.0	6.75	13.0	6.50	12.0	4.40	9.0
7.58	14.4	7.80	13.4	7.10	13.5	7.40	14.0	5.90	10.0
7.85	14.8	8.10	13.8	7.50	14.0	7.75	14.5	7.50	11.0
8.10	15.2	8.30	14.0	7.90	14.5	8.25	15.0	8.00	11.4
8.30	15.6	8.70	14.5	8.30	15.0	8.55	15.5	8.50	11.8
8.50	16.0	9.00	15.0	8.55	15.5	8.80	16.0	8.80	12.0
8.73	16.5	9.20	15.5	8.80	16.0	9.25	17.0	9.00	12.5
8.95	17.0	9.40	16.0	9.10	17.0	9.50	18.0	9.30	13.0
9.20	18.0	9.70	17.0	9.30	18.0	9.70	19.0	9.50	13.5
9.50	19.0	9.85	18.0	9.50	19.0	9.85	20.0	9.80	14.0
9.70	20.0	10.00	19.0	9.65	20.0	10.00	21.0	10.00	14.6
10.00	22.0	10.15	20.0	9.75	21.0	10.15	23.0		
10.25	24.0	10.28	21.0	9.90	23.0	10.25	24.0		
				10.00	25.0				
				10.10	27.0				
				10.25	30.0				

TITRATION CURVE DATA, MAKELA & DENISON SAMPLES July 26,1990

Sample Volume 10 mL Titrant 0.01N NaOH

Straw Pond		Makela 1		Makela 5		Makela 10		Makela 15		Makela 17	
pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL
2.32	0.0	4.65	0.0	2.98	0.0	2.99	0.0	3.00	0.0	2.82	0.0
2.40	2.0	5.72	1.0	3.15	1.0	3.10	1.0	3.32	2.0	2.92	1.0
2.72	4.0	5.95	2.0	3.20	2.0	3.37	3.0	3.65	4.0	3.10	2.0
2.95	6.0	6.10	3.0	3.31	3.0	3.79	5.0	4.60	5.0	3.25	3.0
3.18	8.0	6.19	4.0	3.39	4.0	4.55	6.0	5.01	5.5	3.40	4.0
3.29	10.0	6.29	5.0	3.45	5.0	4.99	6.4	5.44	6.0	3.59	5.0
3.50	12.0	6.35	6.0	3.68	6.0	5.20	6.6	6.00	6.5	4.20	6.0
3.91	14.0	6.42	7.0	4.19	7.0	5.50	6.8	6.85	7.0	5.42	7.0
4.68	16.0	6.49	8.0	4.95	8.0	5.81	7.0	7.13	7.2	6.00	7.4
4.96	17.0	6.58	9.0	5.30	8.4	6.11	7.2	7.35	7.4	6.95	8.0
6.00	18.0	6.62	10.0	5.33	8.8	6.35	7.4	7.59	7.6	7.25	8.2
6.80	19.0	6.68	11.0	5.72	9.2	6.73	7.6	7.82	7.8	7.42	8.4
7.15	19.4	6.78	12.0	5.92	9.6	7.01	7.8	8.08	8.0	7.78	8.6
7.68	20.0	6.92	13.0	6.10	10.0	7.21	8.0	8.28	8.2	7.91	8.8
8.05	20.2	7.12	14.0	6.30	10.5	7.50	8.2	8.49	8.4	8.15	9.0
8.31	20.4	7.79	15.0	6.61	11.0	7.66	8.4	8.62	8.6	8.45	9.4
8.59	20.6	7.98	15.2	6.86	11.4	7.90	8.6	8.84	9.0	8.75	10.0
8.80	20.8	8.15	15.4	7.05	11.6	8.11	8.8	9.10	9.4	9.35	11.0
9.02	21.0	8.32	15.6	7.31	11.8	8.32	9.0	9.32	10.0	9.79	12.0
9.22	21.4	8.50	15.8	7.56	12.0	8.57	9.2	9.72	11.0	10.22	13.2
9.68	22.0	8.69	16.0	7.80	12.2	8.80	9.6	10.15	12.0	10.45	14.0
10.20	23.0	9.00	16.4	8.00	12.4	9.02	10.0	10.38	13.0		
10.50	24.0	9.31	17.0	8.22	12.6	9.45	11.0	10.58	14.0		
		9.52	17.4	8.38	12.8	9.81	12.0				
		9.81	18.0	8.60	13.0	10.18	13.0				
		10.20	19.0	8.88	13.4	10.40	14.0				
				9.22	14.0						
				9.50	14.4						
				9.78	15.0						
				10.10	16.0						
				10.42	17.0						
				10.55	18.0						

TITRATION CURVE DATA, MAKELA SAMPLES of AUG 8,1990

Sample Volume 10 mL Titrant 0.01N NaOH

Makela 1		Makela 6		Makela 11		Makela 14	
pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL
5.20	0.0	3.10	0.0	3.25	0.0	3.15	0.0
5.80	0.8	3.30	1.0	3.30	1.0	3.30	1.0
6.08	1.6	3.42	2.0	3.50	2.0	3.78	3.0
6.20	2.4	3.53	3.0	3.70	3.2	4.10	4.0
6.30	3.2	3.68	5.0	4.00	4.6	4.80	5.0
6.35	4.0	4.15	7.0	4.60	6.0	5.48	6.0
6.41	4.8	4.65	8.0	5.00	7.0	5.80	6.5
6.45	5.6	4.90	8.4	5.50	8.0	6.20	7.0
6.50	6.4	5.15	9.0	6.00	8.6	6.68	7.5
6.60	8.0	5.45	9.5	6.40	9.0	7.28	8.0
6.70	9.6	5.70	10.0	6.85	9.5	7.52	8.4
6.99	12.8	6.05	10.5	7.20	10.0	7.82	8.8
7.45	14.4	6.38	11.0	7.50	10.5	8.14	9.2
7.70	14.8	6.80	11.6	7.81	11.0	8.30	9.5
8.00	15.2	7.30	12.5	8.10	11.5	8.62	10.0
8.30	15.6	7.65	13.0	8.30	12.0	8.82	10.5
8.55	16.0	8.05	13.5	8.50	12.6	9.02	11.0
8.80	16.4	8.32	14.0	8.80	13.3	9.23	11.5
8.91	16.8	8.68	15.0	9.10	14.0	9.35	12.0
9.28	17.6	9.05	16.0	9.35	15.0	9.55	13.0
9.50	18.4	9.35	17.0	9.70	17.0	9.72	14.0
9.70	19.2	9.58	18.0	9.92	19.0	9.87	15.0
9.90	20.0	9.88	20.0	10.00	20.0	9.95	16.0
10.05	20.8	10.10	22.0	10.12	21.0	10.05	17.0
10.18	21.6	10.25	24.0	10.21	22.0	10.15	18.0

TITRATION CURVE DATA, SAMPLES of 21 AUG 1990 STANDARD NUMBERS

ACIDITY - Sample Volume 10 mL, Titrant 0.01N NaOH

ARUM 1 top		ARUM 1 middle		ARUM 1 bottom		ARUM 2 top		ARUM 2 middle		ARUM 2 bottom	
pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL	pH	NaOH mL
6.70	0.0	5.70	0.0	6.70	0.0	6.80	0.0	7.10	0.0	6.25	0.0
7.10	0.2	5.95	0.5	6.90	1.0	7.40	1.0	7.50	0.5	6.40	1.0
7.30	0.4	6.05	1.0	7.10	2.0	7.55	1.4	7.70	1.0	6.60	2.0
7.50	0.6	6.20	2.0	7.25	2.4	7.70	1.8	7.90	1.5	6.90	3.0
7.68	0.8	6.40	3.0	7.45	3.0	7.80	2.0	8.05	1.8	7.00	3.4
7.80	1.0	6.50	4.0	7.65	4.0	7.95	2.4	8.20	2.3	7.30	4.0
7.90	1.2	6.75	5.1	7.80	5.0	8.15	2.8	8.28	2.6	7.50	4.6
8.05	1.4	6.90	6.0	7.90	5.4	8.25	3.2	8.45	3.0	7.70	5.0
8.10	1.6	7.20	7.0	7.95	6.0	8.30	3.4	8.65	4.0	8.05	6.0
8.20	1.8	7.40	7.5	8.05	6.5	8.45	4.0	8.80	5.0	8.20	6.4
8.30	2.0	7.50	8.0	8.10	7.0	8.60	5.1	8.90	6.0	8.30	6.8
8.40	2.4	7.70	8.4	8.15	7.4	8.75	6.0	9.02	7.0	8.50	8.0
8.50	2.6	7.90	8.8	8.20	8.0	8.90	7.0	9.15	8.0	8.80	10.0
8.60	2.8	8.05	9.4	8.25	8.6	9.00	8.0	9.40	10.0	9.10	13.0
8.62	3.0	8.30	10.0	8.30	9.0	9.20	10.0	9.60	12.0	9.30	15.0
8.72	3.6	8.45	11.0	8.50	12.0	9.40	12.0	9.80	14.0	9.50	17.0
9.00	5.0	8.70	13.0	8.60	14.0	9.60	14.0	9.95	16.0	9.70	19.0
9.20	7.0	9.00	15.0	8.70	16.0	9.80	16.0	10.15	18.0	10.00	22.0
9.50	9.0	9.35	19.0	8.90	20.0	10.00	18.0			10.25	25.0
9.80	12.0	9.50	20.0	9.05	24.0	10.20	20.0				
10.10	15.0			9.30	30.0						

ALKALINITY - Sample Volume 10 mL, Titrant 0.02N H2SO4

ARUM 1 top		ARUM 1 middle		ARUM 1 bottom		ARUM 2 top		ARUM 2 middle		ARUM 2 bottom	
pH	H2SO4 mL	pH	H2SO4 mL	pH	H2SO4 mL	pH	H2SO4 mL	pH	H2SO4 mL	pH	H2SO4 mL
7.00	0.0	5.90	0.0	6.80	0.0	6.90	0.0	7.20	0.0	6.50	0.0
6.70	3.5	5.80	1.5	6.75	9.0	6.80	1.0	7.10	0.5	6.40	1.0
6.60	4.0	5.70	2.5	6.70	10.0	6.70	1.5	7.00	1.0	6.20	2.0
6.50	4.5	5.65	3.0	6.70	11.0	6.60	2.0	6.90	1.5	6.00	3.0
6.40	5.0	5.50	3.5	6.60	14.0	6.50	2.5	6.80	2.0	5.80	4.0
6.15	5.5	5.45	4.0	6.50	15.0	6.45	3.0	6.70	2.5	5.70	4.5
5.90	6.0	5.30	5.0	6.40	17.0	6.25	4.0	6.65	3.0	5.55	5.0
5.60	6.5	5.25	5.5	6.35	20.0	6.15	4.5	6.50	3.5	5.45	5.5
5.30	7.0	5.15	6.0	6.30	21.0	6.00	5.0	6.40	4.0	5.30	6.0
5.20	7.3	5.10	6.5	6.15	22.0	5.85	5.5	6.20	5.0	5.10	7.0
5.00	7.5	5.00	7.0	6.00	23.0	5.70	6.0	5.90	6.0	5.00	7.5
4.85	7.8	4.95	7.5	5.90	24.0	5.50	6.5	5.60	7.0	4.82	8.5
4.70	8.0	4.90	8.0	5.70	25.0	5.40	7.0	5.45	7.5	4.75	9.0
4.50	8.3	4.85	8.5	5.50	26.0	5.25	7.5	5.30	8.0	4.68	9.5
4.30	8.5	4.80	9.0	5.35	27.0	5.00	8.5	5.20	8.5	4.52	10.0
4.10	8.8	4.70	10.0	5.20	28.0	4.80	9.5	4.95	9.5	4.50	10.3
3.90	9.0	4.60	10.5	5.10	28.5	4.65	10.0	4.80	10.0	4.40	11.0
3.55	9.5	4.50	11.5	5.00	29.0	4.50	10.3	4.60	10.5	4.20	12.0
3.35	10.0	4.30	13.5	4.90	30.0	4.32	11.0	4.50	11.0	4.00	13.0
		4.00	15.5	4.80	30.5	4.10	12.0	4.30	11.5	3.75	14.0
		3.75	17.1	4.70	31.5	3.72	13.0	4.00	12.5	3.45	15.0
		3.55	18.0	4.55	32.5	3.35	14.0	3.65	13.5	3.15	16.0
				4.50	33.0	3.10	15.0	3.40	14.0	2.95	17.0
				4.30	34.5	2.90	16.0	3.15	15.0		
				4.10	35.5						
				3.85	37.0						
				3.60	38.0						

ACIDITY - Sample Volume 10 mL, Titrant 0.01N NaOH

ARUM 3 top		ARUM 3 middle		ARUM 3 bottom	
pH	NaOH mL	pH	NaOH mL	pH	NaOH mL
4.70	0.0	4.80	0.0	5.00	0.0
4.80	2.0	4.95	2.0	5.10	2.0
5.05	6.0	5.10	4.0	5.25	4.0
5.40	10.0	5.30	6.0	5.40	6.0
5.80	14.0	5.70	10.0	5.65	8.0
6.05	16.0	6.20	14.0	5.80	10.0
6.35	18.0	6.40	16.0	6.00	12.0
6.60	20.0	7.00	20.0	6.15	14.0
6.90	22.0	7.20	21.0	6.20	16.0
7.35	24.0	7.40	21.5	6.40	20.0
7.70	25.0	7.60	22.0	6.50	24.0
7.90	26.0	7.90	23.0	6.65	28.0
8.30	27.0	8.10	23.5	6.80	30.0
8.50	28.0	8.25	24.0	6.90	31.0
8.85	30.0	8.40	24.4	7.10	33.0
9.10	32.0	8.50	25.0	7.50	35.0
9.40	34.0	8.85	27.0	7.75	36.0
9.60	36.0	9.20	29.0	8.00	37.0
9.85	38.0	9.45	31.0	8.20	38.0
10.00	40.0	9.70	33.0	8.30	38.4
		9.85	35.0	8.45	39.0
		10.00	37.0	8.65	40.0
				8.90	42.0
				9.25	44.0

ALKALINITY - Sample Volume 10 mL, Titrant 0.02N H2SO4

ARUM 3 top		ARUM 3 middle		ARUM 3 bottom	
pH	H2SO4 mL	pH	H2SO4 mL	pH	H2SO4 mL
4.75	0.0	4.80	0.0	5.00	0.0
4.70	0.3	4.75	0.3	4.90	0.5
4.65	0.5	4.70	0.5	4.85	1.0
4.60	0.8	4.60	1.0	4.75	2.0
4.50	1.3	4.50	1.5	4.70	2.5
4.40	2.0	4.30	2.5	4.60	3.0
4.30	2.5	4.10	3.5	4.50	3.8
4.25	3.0	4.00	4.0	4.40	4.5
4.05	4.0	3.70	5.0	4.35	5.0
3.80	5.0	3.30	6.0	4.20	6.0
3.50	6.0	3.00	7.0	4.15	6.5
		2.95	8.0	4.00	7.0
		2.90	9.0	3.90	8.0
		2.90	10.0	3.65	9.0
				3.50	9.5
				3.35	10.0

20/09/90 TABLE E-1. pH and REDOX DATA

RANGES of pH, Eh, and pE for VARIOUS SOURCES

SAMPLE SOURCE		Seep	Piez.	Cells	ARUM-1	ARUM-2	ARUM-3
pH, units	MAX	6.40	6.95	6.20	6.74	6.65	6.28
	MIN	5.85	5.11	2.79	6.01	5.61	4.44
Eh, mV	MAX	208	413	690	-34	-31	140
	MIN	159	161	227	-96	-109	27
pE, units	MAX	3.510	6.982	11.658	-0.580	-0.532	2.372
	MIN	2.690	2.712	3.835	-1.622	-1.842	0.452

TABLE E-2. POTENTIAL METAL-SULFIDE PRECIPITATES

MINERAL	COMPOSITION	
ALABANDITE	MnS	
BORNITE	Cu_5FeS_4	
CHALCOCITE	Cu_2S	
CHALCOPYRITE	$CuFeS_2$	
COVELLITE	CuS	
GALENA	PbS	
GREENOCKITE	CdS	
MARCASITE	FeS_2	
NICCOLITE	NiS	
PYRIYTE	FeS_2	(up to 60% Ni, rare)
PYRRHOTITE	$Fe_{1-n}S$	($0<n<0.2$; minor Ni, Co, Mn)
SPHALERITE	ZnS	(up to 28% Fe; minor Mn or Cd)
WURZITE	ZnS	

MAKELA - SEEP and SYSTEM-FEED COMPARISON

SOURCE	SEEPAGE	FEED-1	SEEPAGE	BY-PASSED
DATE	07/07/90	07/07/90	18/07/90	18/07/90
ELEMENTS	TOTAL MOLALITIES OF ELEMENTS			
AL	1.117E-05	1.861E-05	1.489E-05	1.861E-05
BA	1.462E-07	1.463E-07	1.462E-07	1.463E-07
TOT ALK	5.518E-04	2.007E-06	2.007E-06	6.021E-04
CA	1.451E-02	1.446E-02	1.125E-02	1.185E-02
CD	8.935E-07	8.936E-07	2.680E-06	8.935E-07
CL	1.756E-03	2.040E-03	2.039E-03	2.040E-03
CU	1.580E-06	1.581E-06	9.482E-07	1.580E-06
FE	5.395E-03	5.791E-03	4.963E-03	5.125E-03
K	1.926E-03	2.158E-03	2.363E-03	2.106E-03
MG	7.518E-03	8.387E-03	8.922E-03	8.799E-03
MN	8.043E-05	8.776E-05	8.043E-05	8.592E-05
NA	4.368E-03	4.194E-03	5.285E-03	4.718E-03
NI	5.645E-04	4.277E-04	4.789E-04	5.303E-04
PB	1.454E-06	1.939E-06	2.423E-06	1.454E-06
S	2.975E-02	3.155E-02	3.057E-02	3.129E-02
SI	2.674E-04	3.009E-04	2.508E-04	2.841E-04
SR	2.063E-05	2.522E-05	1.375E-05	1.490E-05
ZN	7.681E-06	7.683E-06	7.681E-06	7.682E-06
PARAMETERS	DESCRIPTION OF SOLUTIONS			
pH	4.79	4.06	4.96	5.50
pE	7.9629	9.2954	7.6841	9.2905
H2O Activity	0.9987	0.9990	0.9990	0.9990
Ionic Strength	0.0803	0.0835	0.0775	0.0773
Temperature, C	10.4	11.5	22.0	21.0
Electr.Balance	7.261E-04	-1.780E-04	-4.099E-03	-9.870E-03
THOR	2.670E-01	2.025E-01	1.937E-01	2.177E-01
T.Alkalinity	5.518E-04	2.007E-06	2.007E-06	6.021E-04
Iterations	19	17	14	18
Total Carbon	1.937E-02	3.602E-04	3.715E-05	3.750E-03
MINERALS	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)
ALOH3(A)	-3.3172	-5.2115	-1.9536	-0.5293
ALOHSO4	-0.3864	-0.8848	-0.1684	0.2781
AL4(OH)1	-2.0653	-8.4882	-0.2146	4.7092
ALUM K	-7.9330	-7.6583	-8.0044	-8.0970
ALUNITE	4.2966	0.6300	5.4119	8.2962
ANHYDRIT	-0.0154	0.0009	-0.0214	0.0132
ARAGONIT	-3.2575	-6.4172	-5.4662	-2.4480
ARTINITE	-15.4845	-19.9382	-16.3372	-12.3490
BARITE	0.8681	0.8608	0.6892	0.7400
BOEHMITE	-1.5574	-3.4486	-0.1612	1.2604
BRUCITE	-10.8351	-12.1797	-9.6592	-8.6625
CALCITE	-3.0638	-6.2287	-5.3185	-2.2969
CELESTIT	-0.7472	-0.6472	-0.8978	-0.8292
CHALCEDO	0.1302	0.1679	-0.0378	0.0281
CHRYSOTI	-20.5077	-24.5133	-17.7951	-14.6333
CLINOENS	-8.7283	-10.0390	-7.7575	-6.6918
CRISTOBA	0.2338	0.2688	0.0388	0.1069

MAKELA - SEEP and SYSTEM-FEED COMPARISON

SOURCE DATE	SEEPAGE 07/07/90	FEED-1 07/07/90	SEEPAGE 18/07/90	BY-PASSED 18/07/90
DIASPORE	0.2847	-1.6169	1.5749	3.0053
DIOPSIDE	-14.1175	-16.8119	-12.5976	-10.4185
DOLOMITE	-6.5124	-12.7740	-10.6822	-4.6772
EPSOMITE	-2.5275	-2.4801	-2.5449	-2.5222
SEPIOLIT	-15.6119	-18.3007	-14.9105	-12.6242
FERRIHYD	1.2245	0.4152	1.6792	3.9882
FE3(OH)8	-1.2314	-4.2917	-0.0616	4.7443
FEOH)2.7	6.8581	6.2868	7.2811	9.4283
FES PPT	-67.1018	-72.0666	-68.1195	-85.9972
FE2(SO4)	-28.6825	-25.6955	-26.9612	-25.6295
FORSTERI	-19.8333	-22.4807	-17.6061	-15.5503
GIBBSITE	-1.5468	-3.4537	-0.3119	1.1231
GOETHITE	5.0686	4.3023	5.9617	8.2343
GREENALI	-7.6282	-11.8507	-6.9039	-6.2318
GREIGITE	-247.1370	-264.2896	-251.0795	-318.5357
GYPSUM	0.3456	0.3501	0.2178	0.2625
HALITE	-6.8821	-6.8412	-6.7649	-6.8126
HEMATITE	15.0664	13.5393	16.9098	21.4503
HUNTITE	-17.6582	-30.1042	-25.5327	-13.5739
HYDRMAGN	-33.1855	-46.9239	-39.6779	-26.7522
JAROSITE	4.9508	5.6404	7.3331	12.0296
MACKINAW	-66.3718	-71.3366	-67.3895	-85.2672
MAGADIIT	-8.3306	-8.7203	-8.2785	-7.4089
MAGHEMIT	5.8407	4.2217	6.7496	11.3678
MAGNESIT	-3.9311	-7.0309	-5.8611	-2.8778
MAGNETIT	13.3564	10.4460	16.0541	20.7332
MELANTER	-2.3565	-2.3294	-2.5080	-3.3591
MIRABILI	-5.2435	-5.3214	-5.6421	-5.6614
NATRON	-12.1243	-15.3658	-14.6084	-11.6529
NESQUEHO	-6.3284	-9.4290	-8.2695	-5.2853
PHLOGOPI	-49.4265	-55.9386	-44.9188	-39.8065
PYRITE	-104.4021	-111.7183	-107.2574	-138.8794
QUARTZ	0.6810	0.7138	0.4642	0.5341
SIDERITE	-1.5399	-4.6624	-3.6282	-1.5166
SIO2(A,G	-0.7153	-0.6746	-0.8511	-0.7879
SIO2(A,P	-0.7153	-0.6746	-0.8511	-0.7879
STRONTIA	-4.9337	-8.0063	-7.2615	-4.2105
TALC	-17.8449	-21.8001	-15.7188	-12.4044
THENARDI	-6.9061	-6.9270	-6.7137	-6.7819
THERMONA	-14.2590	-17.4463	-16.1828	-13.2736
TREMOLIT	-39.6782	-49.0309	-34.6019	-26.9218
WITHERIT	-7.7035	-10.8664	-9.8870	-6.8681
PYROLUSI	-13.0100	-13.0735	-11.2508	-5.9984
BIRNESSI	-14.1387	-14.2891	-13.2634	-7.9375
NSUTITE	-13.5487	-13.6991	-12.6734	-7.3475
BIXBYITE	-17.5579	-19.0184	-15.1281	-8.8075
HAUSMANN	-24.2746	-27.1276	-21.1271	-13.7422
PYROCROI	-11.0149	-12.3798	-10.0180	-8.9769
MANGANIT	-8.5616	-9.3145	-7.5775	-4.3980
RHODOCHR	-3.3992	-6.5218	-5.5336	-2.5038
MNCL2, 4	-12.4378	-12.3350	-12.8622	-12.8000
MNS GREE	-76.8822	-81.8202	-77.6723	-94.6545
MNSO4	-10.0267	-9.9362	-9.5714	-9.5583
MN2(SO4)	-48.4588	-45.4186	-46.2859	-43.1630
CU METAL	-10.2660	-12.9686	-10.4010	-13.3916

MAKELA - SEEP and SYSTEM-FEED COMPARISON

SOURCE DATE	SEEPAGE 07/07/90	FEED-1 07/07/90	SEEPAGE 18/07/90	BY-PASSED 18/07/90
NANTOKIT	-7.4381	-8.7236	-7.5707	-8.9727
CUPRITE	-12.0543	-16.1708	-11.6929	-13.4520
CHALCOCI	-55.1493	-62.9171	-57.3716	-77.0878
DJURLEIT	-54.7827	-62.3714	-56.9892	-76.5085
ANILITE	-53.8550	-60.9439	-56.0097	-74.9810
BLAUBLEI	-52.1524	-57.3914	-53.2705	-70.3767
COVELLIT	-50.6708	-55.7166	-52.5595	-69.3015
CU2SO4	-23.7626	-26.3702	-23.4001	-26.2323
CUPROUSF	7.9720	5.1249	8.8168	10.2289
MELANOTH	-16.3297	-16.1579	-16.0510	-15.8983
CUCO3	-5.8539	-9.0017	-8.2474	-5.0472
CU(OH)2	-6.0411	-7.4469	-5.4625	-4.2378
ATACAMIT	-9.3511	-11.4046	-8.6572	-6.7178
ANTLERIT	-10.4668	-13.3438	-10.4431	-7.6997
BROCHANT	-14.3424	-18.6706	-14.2021	-10.1956
LANGITE	-17.2878	-21.4979	-15.9476	-12.0408
TENORITE	-5.0202	-6.4261	-4.4420	-3.2173
CUOCUSO4	-18.2235	-19.5435	-17.2389	-15.8481
CUSO4	-12.2203	-12.1409	-11.8804	-11.7089
CHALCANT	-5.8341	-5.8125	-6.0866	-5.8660
DIOPTASE	-7.2275	-8.6006	-6.8679	-5.5730
CUPRICFE	8.0655	5.1105	10.2629	16.0468
CHALCOPY	-109.0298	-119.0745	-112.2835	-146.8743
ZN METAL	-48.8208	-51.3893	-47.1736	-50.4952
ZNCL2	-19.1669	-19.0013	-18.5328	-18.5924
SMITHSON	-4.9909	-8.1474	-7.0531	-4.0633
ZNCO3, 1	-4.5669	-7.7362	-6.7611	-3.7603
ZN(OH)2	-7.6680	-9.1408	-7.3522	-6.2885
ZN2(OH)3	-15.1906	-17.3430	-14.6646	-13.0768
ZN5(OH)8	-34.6493	-40.4269	-33.2813	-29.0421
ZN2(OH)2	-11.5361	-13.0052	-11.2308	-10.1492
ZN4(OH)6	-24.7722	-29.1868	-23.8352	-20.6262
ZNO(ACTI	-7.4775	-8.9504	-7.1618	-6.0980
ZINCITE	-8.1325	-9.5402	-7.1546	-6.1459
ZN3O(SO4	-33.2636	-34.5444	-31.0908	-30.1475
ZNS (A)	-64.7709	-69.7777	-65.8443	-82.8369
SPHALERI	-62.0281	-67.0485	-63.2402	-80.2213
WURTZITE	-64.0884	-69.0994	-65.2040	-82.1931
ZNSIO3	-3.3507	-4.7179	-2.5101	-1.4380
WILLEMIT	-12.4880	-15.2831	-10.8744	-8.7766
ZINCOSIT	-11.6027	-11.5418	-11.0316	-11.0621
ZNSO4, 1	-7.7002	-7.6647	-7.3883	-7.3972
BIANCHIT	-6.1175	-6.1126	-6.1223	-6.1050
GOSLARIT	-5.7875	-5.7927	-5.8969	-5.8710
CD METAL	-36.8487	-39.4724	-35.2906	-39.0494
GAMMA CD	-36.9540	-39.5772	-35.3917	-39.1508
OTAVITE	-2.1149	-5.2819	-3.8119	-1.2970
CDCL2	-11.9725	-11.8450	-11.2528	-11.7641
CDCL2, 1	-10.8431	-10.7233	-10.2035	-10.7081
CDCL2,2.	-10.4807	-10.3713	-9.9478	-10.4436
CD(OH)2	-10.8247	-12.2967	-10.0292	-9.4499
CDOHCL	-8.6289	-9.2857	-7.7145	-7.6936
CD3(OH)4	-25.7841	-28.7237	-23.7238	-23.0319
CD3OH2(S	-21.6342	-23.0974	-19.9002	-20.2541
CD4(OH)6	-28.7988	-33.2105	-25.9430	-24.6717

MAKELA - SEEP and SYSTEM-FEED COMPARISON

SOURCE DATE	SEEPAGE 07/07/90	FEED-1 07/07/90	SEEPAGE 18/07/90	BY-PASSED 18/07/90
MONTEPON	-13.2285	-14.6270	-11.6832	-11.1662
CDSIO3	-10.4255	-11.7968	-9.1548	-8.5631
CDSO4	-9.3311	-9.2827	-8.4153	-8.9190
CDSO4, 1	-7.4991	-7.4722	-6.8020	-7.2875
CDSO4,2.	-7.1685	-7.1510	-6.5687	-7.0462
GREENOCK	-58.4186	-63.4625	-59.3967	-76.8418
PB METAL	-26.8870	-29.4256	-26.1157	-29.5992
COTUNNIT	-7.4552	-7.2179	-7.2699	-7.5269
PHOSGENI	-8.4123	-11.1871	-10.0013	-7.5272
CERRUSIT	-2.4723	-5.5157	-4.5635	-1.8060
MASSICOT	-10.6701	-11.9525	-9.5959	-8.8299
LITHARGE	-10.4650	-11.7486	-9.4029	-8.6359
PBO, .3H	-10.1070	-11.4393	-9.5410	-8.7328
PB2OCO3	-12.8450	-17.1722	-13.8760	-10.3513
LARNAKIT	-5.9174	-7.0863	-4.9165	-4.3622
PB3O2SO4	-14.2643	-16.7229	-12.2640	-10.9375
PB4O3SO4	-23.6316	-27.3799	-20.6316	-18.5329
PB3O2CO3	-22.0569	-27.6718	-22.0684	-17.7732
PBSIO3	-8.3600	-9.6135	-7.5420	-6.7028
PB2SIO4	-18.5587	-21.0946	-16.6676	-15.0624
ANGLESIT	-0.9564	-0.8185	-0.7816	-1.0139
GALENA	-59.0566	-63.9697	-60.3562	-77.5648
PLATTNER	-23.5910	-23.5075	-21.1000	-16.1771
PB2O3	-29.7884	-31.2480	-28.8740	-22.9648
MINIUM	-43.4435	-45.9293	-38.8504	-32.3917
PB(OH)2	-5.8054	-7.0959	-4.8155	-4.0426
LAURIONI	-5.4020	-5.9411	-4.9415	-4.6729
PB2(OH)3	-10.6994	-12.5707	-9.6727	-8.5961
HYDCERRU	-11.2388	-18.6289	-14.5608	-8.2620
PB2O(OH)	-20.4542	-23.1188	-19.3222	-17.7058
PB4(OH)6	-21.3097	-25.1621	-19.3715	-17.1847
NICO3	-6.4428	-9.6945	-8.3997	-5.3861
NI(OH)2	-3.9002	-5.5755	-4.5704	-3.3922
NI4(OH)6	-20.6975	-25.5596	-20.0152	-16.6550
BUNSENIT	-7.6015	-9.1151	-6.6250	-5.5836
MILLERIT	-63.9064	-69.0216	-65.0080	-81.9658
RETGERSI	-3.8713	-3.9820	-3.9779	-3.9197
MORENOSI	-3.4824	-3.5985	-3.6446	-3.5818
NI2SIO4	-7.8603	-10.8792	-6.3743	-4.2009
ANALCIME	-4.3074	-6.8613	-2.8777	-0.8446
HALLOYSI	-1.4489	-5.1778	0.7860	3.7794
KAOLINIT	1.9790	-1.7631	4.0791	7.0837
LEONHARD	-1.5119	-11.6895	3.4351	11.8041
LOW ALBI	-3.5353	-6.0541	-2.2989	-0.1978
ANALBITE	-4.5534	-7.0645	-3.2383	-1.1437
MUSCOVIT	0.2804	-5.9973	3.8785	8.8583
ANNITE	-6.1191	-12.7532	-2.6349	-0.0924
ANORTHIT	-11.8675	-16.9760	-8.4901	-4.4845
PYROPHYL	3.5136	-0.2310	4.4880	7.6901
LAUMONTI	-7.2645	-12.3301	-4.5556	-0.3906
WAIRAKIT	-12.1527	-17.1807	-9.0594	-4.9263
MALACHIT	-7.7186	-12.2711	-9.5226	-5.0986
AZURITE	-11.7704	-19.4465	-15.7208	-8.1171
SULFUR	-50.3352	-52.6406	-51.7034	-65.4868
LIME	-27.3583	-28.6921	-25.7511	-24.7776

MAKELA - SEEP and SYSTEM-FEED COMPARISON

SOURCE DATE	SEEPAGE 07/07/90	FEED-1 07/07/90	SEEPAGE 18/07/90	BY-PASSED 18/07/90
PORTLAND	-16.6412	-18.0213	-15.5055	-14.4929
WUSTITE	-4.8648	-6.0923	-3.8771	-3.5342
PERICLAS	-15.9429	-17.2569	-14.4554	-13.4846
HERCYNIT	-7.1781	-12.3366	-3.4562	-0.4807
SPINEL	-16.5926	-21.6989	-12.4129	-8.5904
MAG-FERR	-0.1237	-2.9658	3.1969	8.7091
WOLLASTO	-10.1121	-11.4742	-9.3439	-8.2487
P-WOLLST	-11.0213	-12.3788	-10.2056	-9.1144
CA-OLIVI	-28.9026	-31.6315	-26.8626	-24.7660
LARNITE	-30.4888	-33.2101	-28.3716	-26.2814
CA3SIO5	-59.8839	-63.9306	-56.0738	-53.0172
MONTICEL	-21.5806	-24.2753	-19.5131	-17.4314
AKERMINI	-36.1765	-40.2110	-33.1131	-29.9551
MERWINIT	-51.2164	-56.6311	-47.0181	-42.8473
KALSILIT	-7.4626	-9.9836	-5.8173	-3.8543
LEUCITE	-4.3482	-6.8382	-2.9385	-0.9040
MICROCLI	-1.7432	-4.2110	-0.6579	1.4555
H SANIDI	-2.2564	-4.7185	-1.1123	0.9962
NEPHELIN	-8.6341	-11.2086	-6.8623	-4.9095
GEHLENIT	-34.2222	-40.7182	-29.2332	-24.3063
LEPIDOCR	4.7451	3.9357	5.1996	7.5087
NA-NONTR	17.0841	14.7545	18.1510	23.6225
K-NONTRO	18.0120	15.7042	19.0799	24.5512
CA-NONTR	23.8951	21.5701	24.9133	30.4030
MG-NONTR	23.5527	21.2359	24.6017	30.0869
FE(OH)3S	3.4445	2.6352	3.8992	6.2082
PREHNITE	-16.7227	-23.2294	-12.9442	-7.8129
PHILLIPS	-2.4242	-4.9616	-1.7131	0.4315
ILLITE	-4.9768	-9.9568	-2.0662	1.9899
MONTMORI	-3.4517	-7.9723	-0.7998	2.9414
CHLORITE	-32.2160	-42.6774	-24.7488	-16.6660
CHLORT-M	-12.9196	-23.5017	-10.0709	-1.9973
CHLORT-F	17.3498	6.2393	20.0426	26.5388
NA2SO3	-37.6315	-38.8504	-37.1493	-41.5162
K2SO3	-41.6021	-42.6910	-41.1372	-45.5034
CASO3.2H	-26.4243	-27.6332	-26.4192	-30.6603
CASO3.5H	-26.8937	-28.0925	-26.7842	-31.0340
MGSO3	-37.4701	-38.5654	-36.6280	-40.9512
BASO3	-29.3181	-30.5249	-29.2226	-33.4693
CH4(GAS)	-77.2988	-83.9973	-80.7864	-95.8669
CO2(GAS)	-0.4789	-2.1770	-3.0049	-1.0665
O2(GAS)	-37.2660	-34.4488	-33.5623	-25.3207

MAKELA - ARUMATOR #1 COMPARISON

SOURCE	ARUM-1-HOMO	ARUM-1-TOP	ARUM-1-MID	ARUM-1-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
ELEMENTS	TOTAL MOLALITIES OF ELEMENTS			
AL	3.346E-05	5.580E-05	5.958E-05	5.969E-05
BA	3.652E-07	7.308E-07	7.316E-07	7.329E-07
TOT ALK	8.678E-03	1.901E-02	3.514E-02	7.233E-02
CA	1.266E-02	1.590E-02	1.589E-02	1.622E-02
CD	2.677E-07	1.786E-07	1.788E-07	1.791E-07
CL	1.980E-03	1.982E-03	1.984E-03	1.987E-03
CU	4.735E-07	4.739E-07	6.325E-07	4.752E-07
FE	4.490E-05	4.978E-05	1.979E-05	3.244E-04
K	2.001E-03	5.134E-03	5.114E-03	5.483E-03
MG	5.198E-03	8.546E-03	8.514E-03	8.984E-03
MN	1.022E-04	1.827E-04	1.811E-04	1.832E-04
NA	3.796E-03	6.855E-03	6.818E-03	7.093E-03
NI	5.125E-06	1.881E-05	5.134E-06	5.143E-06
PB	9.682E-07	9.689E-07	4.850E-07	9.716E-07
S	1.749E-02	1.515E-02	1.787E-02	1.594E-02
SI	2.171E-04	3.175E-04	3.178E-04	3.184E-04
SR	1.717E-05	2.864E-05	2.867E-05	2.987E-05
ZN	6.137E-07	1.535E-07	1.537E-07	3.079E-07
PARAMETERS	DESCRIPTION OF SOLUTIONS			
pH	6.01	6.65	5.87	6.59
pE	-1.5710	-1.8644	-0.5311	-1.4564
H2O Activity	0.9990	0.9988	0.9972	0.9974
Ionic Strength	0.0559	0.0705	0.0806	0.0975
Temperature, C	22.0	21.5	21.0	21.0
Electr.Balance	-3.748E-03	1.016E-02	-1.157E-02	-4.210E-02
THOR	-3.704E+01	-7.298E+01	-2.824E+00	-2.809E+01
T.Alkalinity	8.678E-03	1.901E-02	3.514E-02	7.233E-02
Iterations	17	16	18	12
Total Carbon	2.365E-02	2.618E-02	1.163E-01	1.036E-01
MINERALS	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)
ALOH3(A)	0.5774	0.9706	0.6333	0.9693
ALOHSO4	0.0730	-0.9150	0.4195	-0.7469
AL4(OH)1	7.6197	7.9134	8.3382	8.1797
ALUM K	-9.0546	-10.4059	-8.2225	-10.1464
ALUNITE	9.4240	8.9241	10.5051	9.2518
ANHYDRIT	-0.0809	-0.1130	-0.0868	-0.1789
ARAGONIT	-0.6100	0.4506	-0.1155	0.8831
ARTINITE	-9.8400	-7.2009	-9.4168	-6.9985
BARITE	0.9377	1.0830	1.1513	1.0659
BOEHMITE	2.3698	2.7618	2.4238	2.7596
BRUCITE	-7.7237	-6.2570	-7.9008	-6.4860
CALCITE	-0.4622	0.6000	0.0355	1.0341
CELESTIT	-0.9503	-0.8926	-0.8328	-0.9012
CHALCEDO	-0.1026	0.0697	0.0786	0.0806
CHRYSOTI	-12.1181	-7.3533	-12.2466	-7.9980
CLINOENS	-5.8868	-4.2461	-5.8789	-4.4621
CRISTOBA	-0.0260	0.1475	0.1574	0.1595

MAKELA - ARUMATOR #1 COMPARISON

SOURCE	ARUM-1-HOMO	ARUM-1-TOP	ARUM-1-MID	ARUM-1-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
DIASPORE	4.1059	4.5022	4.1686	4.5045
DIOPSIDE	-8.5616	-5.3819	-8.6332	-5.8041
DOLOMITE	-1.2642	0.9667	-0.1719	1.8299
EPSOMITE	-2.8993	-2.8123	-2.7871	-2.8739
SEPIOLIT	-11.2340	-7.7361	-10.9506	-8.1145
FERRIHYD	-6.3762	-4.7067	-6.1564	-3.7129
FE3(OH)8	-16.0228	-11.3481	-16.2373	-8.7015
FEOH)2.7	-1.0891	0.3858	-0.8313	1.3940
FES PPT	-4.6184	-7.3948	-12.0948	-9.3064
FE2(SO4)	-49.9408	-50.9214	-48.9825	-48.6025
FORSTERI	-13.7998	-10.6957	-13.9751	-11.1435
GIBBSITE	2.2191	2.6176	2.2857	2.6216
GOETHITE	-2.0937	-0.4422	-1.9096	0.5339
GREENALI	-6.5844	-2.2443	-8.2069	-0.2566
GREIGITE	-13.6352	-25.4086	-41.1387	-33.0444
GYPSUM	0.1582	0.1310	0.1610	0.0691
HALITE	-6.8933	-6.6500	-6.6638	-6.6637
HEMATITE	0.7990	4.0997	1.1633	6.0501
HUNTITE	-6.9912	-2.4295	-4.7227	-0.7147
HYDRMAGN	-19.4955	-13.3569	-17.3020	-11.8742
JAROSITE	-21.4124	-19.3035	-20.4483	-16.1222
MACKINAW	-3.8884	-6.6648	-11.3648	-8.5764
MAGADIIT	-7.8113	-5.7546	-6.5268	-5.7841
MAGHEMIT	-9.3611	-6.0218	-8.9192	-4.0324
MAGNESIT	-1.2994	-0.1308	-0.7049	0.2983
MAGNETIT	0.0931	4.7048	-0.2454	7.2901
MELANTER	-4.6481	-4.7247	-5.0779	-3.9308
MIRABILI	-6.0901	-5.7003	-5.6267	-5.6723
NATRON	-10.1406	-8.6626	-9.1857	-8.1407
NESQUEHO	-3.7079	-2.5391	-3.1147	-2.1113
PHLOGOPI	-35.7771	-29.4171	-35.4409	-30.1110
PYRITE	3.1848	-2.9964	-9.2871	-6.7696
QUARTZ	0.3994	0.5737	0.5846	0.5867
SIDERITE	-0.8522	0.1539	-0.7977	1.4394
SIO2(A,G	-0.9159	-0.7449	-0.7374	-0.7353
SIO2(A,P	-0.9159	-0.7449	-0.7374	-0.7353
STRONTIA	-2.3982	-1.2485	-1.7817	-0.7593
TALC	-10.1714	-5.0514	-9.9160	-5.6634
THENARDI	-7.1613	-6.7952	-6.7395	-6.7862
THERMONA	-11.7147	-10.2591	-10.7995	-9.7555
TREMOLIT	-20.9824	-9.4994	-20.8628	-10.9520
WITHERIT	-4.7227	-3.4925	-4.0244	-3.0190
PYROLUSI	-25.3895	-23.2429	-23.8271	-22.8590
BIRNESSI	-27.4021	-25.2188	-25.7663	-24.7982
NSUTITE	-26.8121	-24.6288	-25.1763	-24.2082
BIXBYITE	-26.9953	-23.3410	-25.5611	-23.2143
HAUSMANN	-30.7227	-25.5627	-29.4206	-25.6952
PYROCROI	-7.7465	-6.2524	-7.9025	-6.5238
MANGANIT	-13.5111	-11.6744	-12.7752	-11.6018
RHODOCHR	-0.6359	0.5611	-0.0182	0.9489
MNCL2, 4	-12.6897	-12.4435	-12.4947	-12.5709
MNS GREE	-12.0494	-14.6463	-18.9854	-17.4671
MNSO4	-9.5895	-9.5016	-9.5051	-9.6287
MN2(SO4)	-65.0220	-65.6433	-62.9824	-65.1425
CU METAL	3.7891	4.1047	2.9161	3.7191

MAKELA - ARUMATOR #1 COMPARISON

SOURCE	ARUM-1-HOMO	ARUM-1-TOP	ARUM-1-MID	ARUM-1-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
NANTOKIT	-2.6353	-2.6309	-2.5003	-2.6302
CUPRITE	0.2769	1.5662	0.2595	1.4549
CHALCOCI	17.9495	15.1808	11.2176	12.5528
DJURLEIT	17.3954	14.6056	10.7206	12.0027
ANILITE	15.7639	12.9149	9.2475	10.3818
BLAUBLEI	9.2796	6.1861	3.2517	3.8642
COVELLIT	8.5716	5.4790	2.6962	3.2283
CU2SO4	-13.7199	-13.8595	-13.5428	-13.8496
CUPROUSF	6.7463	9.0520	6.9412	9.9823
MELANOTH	-20.3701	-20.6941	-19.2613	-20.3241
CUCO3	-7.8414	-7.1750	-6.2329	-6.2520
CU(OH)2	-7.6828	-6.7127	-6.8348	-6.4422
ATACAMIT	-14.1472	-12.8410	-12.2948	-12.2373
ANTLERIT	-19.3934	-17.8409	-16.5119	-16.8366
BROCHANT	-25.3726	-22.8308	-21.6047	-21.5368
LANGITE	-27.1182	-24.6262	-23.4507	-23.3827
TENORITE	-6.6623	-5.6921	-5.8135	-5.4210
CUOCUSO4	-23.9689	-23.4502	-22.0625	-22.7798
CUSO4	-16.3903	-16.8390	-15.3271	-16.4369
CHALCANT	-10.5966	-11.0212	-9.4880	-10.5973
DIOPTASE	-9.1529	-8.0084	-8.1195	-7.7249
CUPRICFE	-8.0681	-3.7880	-6.8365	-1.5572
CHALCOPY	12.3487	6.4940	-0.9743	2.3462
ZN METAL	-29.6579	-29.7594	-32.4529	-30.5169
ZNCL2	-19.5262	-20.2081	-20.2209	-20.1506
SMITHSON	-3.3215	-3.0120	-3.5145	-2.4006
ZNCO3, 1	-3.0295	-2.7146	-3.2123	-2.0982
ZN(OH)2	-6.2468	-5.6091	-7.1510	-5.6253
ZN2(OH)3	-13.5032	-12.8766	-15.1848	-12.8611
ZN5(OH)8	-29.8532	-27.9622	-34.1205	-27.9476
ZN2(OH)2	-11.3096	-11.4492	-12.8954	-11.3464
ZN4(OH)6	-21.7032	-20.5673	-25.0973	-20.4971
ZNO(ACTI	-6.0564	-5.4185	-6.9598	-5.4342
ZINCITE	-6.0492	-5.4388	-7.0076	-5.4821
ZN3O(SO4	-32.3538	-33.3486	-34.7765	-33.2044
ZNS (A)	-1.3876	-4.8572	-9.1047	-7.4395
SPHALERI	1.2166	-2.2474	-6.4891	-4.8238
WURTZITE	-0.7472	-4.2151	-8.4609	-6.7956
ZNSIO3	-1.4694	-0.6880	-2.2493	-0.7216
WILLEMIT	-8.7283	-7.3280	-10.4495	-7.3963
ZINCOSIT	-12.2158	-13.0173	-12.9458	-12.9225
ZNSO4, 1	-8.5725	-9.3633	-9.2817	-9.2583
BIANCHIT	-7.3067	-8.0848	-7.9933	-7.9694
GOSLARIT	-7.0813	-7.8552	-7.7600	-7.7360
CD METAL	-17.9872	-17.4659	-20.2467	-18.6322
GAMMA CD	-18.0882	-17.5671	-20.3481	-18.7336
OTAVITE	-0.2925	0.6209	0.0122	0.8046
CDCL2	-12.4585	-12.5249	-12.6321	-12.8834
CDCL2, 1	-11.4092	-11.4723	-11.5769	-11.8281
CDCL2,2.	-11.1536	-11.2124	-11.3136	-11.5646
CD(OH)2	-9.1360	-7.8991	-9.5519	-8.3478
CDOHCL	-7.8708	-7.2920	-8.1786	-7.7022
CD3(OH)4	-23.3338	-21.0382	-24.3591	-22.2492
CD3OH2(S	-21.7998	-20.9193	-22.6026	-21.9950
CD4(OH)6	-24.6598	-21.1273	-26.1010	-22.7870

MAKELA - ARUMATOR #1 COMPARISON

SOURCE DATE	ARUM-1-HOMO 07/07/90	ARUM-1-TOP 08/08/90	ARUM-1-MID 08/08/90	ARUM-1-BOT 08/08/90
MONTEPON	-10.7900	-9.5841	-11.2675	-10.0635
CDSIO3	-8.3264	-6.9437	-8.6138	-7.4078
CDSO4	-9.8117	-10.0085	-10.0423	-10.3405
CDSO4, 1	-8.1984	-8.3862	-8.4115	-8.7097
CDSO4,2.	-7.9652	-8.1490	-8.1714	-8.4694
GREENOCK	4.8478	1.9933	-2.3492	-1.0055
PB METAL	-8.3481	-8.3574	-11.1373	-9.6880
COTUNNIT	-8.0114	-8.6189	-8.7358	-9.1522
PHOSGENI	-6.7593	-7.0134	-7.7676	-7.5568
CERRUSIT	-0.5799	-0.2135	-0.8376	-0.2103
MASSICOT	-8.2385	-7.5763	-9.2720	-8.2331
LITHARGE	-8.0455	-7.3828	-9.0780	-8.0391
PBO, .3H	-8.1836	-7.5004	-9.1751	-8.1363
PB2OCO3	-8.5350	-7.5058	-9.8249	-8.1589
LARNAKIT	-4.4914	-4.5481	-6.2683	-5.6929
PB3O2SO4	-10.4814	-9.8729	-13.2856	-11.6714
PB4O3SO4	-17.4916	-16.2178	-21.3231	-18.6700
PB3O2CO3	-15.3700	-13.6763	-17.6889	-14.9840
PBSIO3	-6.2495	-5.4112	-7.0944	-6.0535
PB2SIO4	-14.0176	-12.5172	-15.8960	-13.8162
ANGLESIT	-1.7139	-2.4431	-2.4779	-2.9414
GALENA	4.3525	0.9480	-3.4129	-2.2344
PLATTNER	-36.1529	-34.8654	-35.5231	-34.8948
PB2O3	-42.5694	-40.5098	-42.7528	-41.0857
MINIUM	-51.1885	-48.5746	-52.6218	-49.9158
PB(OH)2	-3.4582	-2.7926	-4.4854	-3.4464
LAURIONI	-4.6335	-4.5992	-5.4988	-5.1875
PB2(OH)3	-8.0075	-7.2900	-9.8647	-8.5145
HYDCERRU	-5.2362	-3.8323	-6.7680	-4.4746
PB2O(OH)	-16.6074	-15.2410	-18.5906	-16.5129
PB4(OH)6	-16.2317	-14.9141	-19.9772	-17.3238
NICO3	-5.8586	-4.9429	-5.7619	-5.4972
NI(OH)2	-4.6554	-3.3663	-5.1792	-4.5028
NI4(OH)6	-22.6451	-19.0566	-24.8244	-23.6211
BUNSENIT	-6.7100	-5.4891	-7.3699	-6.6936
MILLERIT	-1.7418	-4.5997	-9.1582	-8.3421
RETGERSI	-6.3528	-6.5161	-6.7325	-7.5578
MORENOSI	-6.0195	-6.1806	-6.3954	-7.2206
NI2SIO4	-6.6092	-3.9825	-7.7229	-6.3682
ANALCIME	0.4447	2.0674	0.9515	2.0193
HALLOYSI	5.7183	6.8561	6.2063	6.8822
KAOLINITE	9.0115	10.1548	9.5106	10.1866
LEONHARD	17.5006	23.2104	18.7014	22.8822
LOW ALBI	0.9587	2.7549	1.6496	2.7193
ANALBITE	0.0193	1.8123	0.7037	1.7734
MUSCOVIT	12.2755	15.0265	13.2641	15.0214
ANNITE	1.1493	7.0446	-0.0887	8.9429
ANORTHIT	-1.3276	1.1593	-1.1341	0.9518
PYROPHYL	9.2908	10.8117	10.2187	10.8986
LAUMONTI	2.4772	5.3223	3.0576	5.1481
WAIRAKIT	-2.0265	0.8028	-1.4765	0.6138
MALACHIT	-11.3368	-9.7008	-8.8813	-8.5079
AZURITE	-17.1290	-14.8368	-13.0855	-12.7312
SULFUR	-4.7623	-8.1866	-9.7968	-10.0676
LIME	-23.5210	-22.1913	-23.8556	-22.4454

MAKELA - ARUMATOR #1 COMPARISON

SOURCE DATE	ARUM-1-HOMO 07/07/90	ARUM-1-TOP 08/08/90	ARUM-1-MID 08/08/90	ARUM-1-BOT 08/08/90
PORTLAND	-13.2755	-11.9263	-13.5717	-12.1613
WUSTITE	-4.6050	-3.3346	-5.1910	-2.7045
PERICLAS	-12.5199	-11.0660	-12.7222	-11.3074
HERCYNIT	1.7556	3.8475	1.1552	4.4755
SPINEL	-5.4152	-3.1733	-5.5006	-3.4142
MAG-FERR	-10.9783	-6.2234	-10.8155	-4.5140
WOLLASTO	-7.1787	-5.6487	-7.2763	-5.8640
P-WOLLST	-8.0404	-6.5124	-8.1420	-6.7297
CA-OLIVI	-22.4672	-19.5937	-22.8716	-20.0491
LARNITE	-23.9762	-21.1059	-24.3870	-21.5645
CA3SIO5	-49.4483	-45.2518	-50.2009	-45.9682
MONTICEL	-15.4123	-12.4207	-15.6966	-12.8696
AKERMINI	-26.8470	-22.3349	-27.2479	-23.0086
MERWINIT	-38.5218	-32.6605	-39.2181	-33.5686
KALSILIT	-2.3526	-0.7512	-1.8762	-0.7947
LEUCITE	0.4613	2.2379	1.1246	2.2081
MICROCLI	2.6771	4.6326	3.5346	4.6202
H SANIDI	2.2227	4.1757	3.0752	4.1608
NEPHELIN	-3.4751	-2.0318	-3.1631	-2.0975
GEHLENIT	-19.7757	-16.1247	-20.0845	-16.5904
LEPIDOCR	-2.8558	-1.1861	-2.6352	-0.1918
NA-NONTR	2.9415	7.3272	4.0796	9.3251
K-NONTRO	3.8960	8.3321	5.0848	10.3355
CA-NONTR	9.7678	14.0885	10.8367	16.0747
MG-NONTR	9.4077	13.7467	10.4942	15.7329
FE(OH)3S	-4.1562	-2.4867	-3.9364	-1.4929
PREHNITE	-3.6164	0.4156	-3.4909	0.0074
PHILLIPS	1.5831	3.4775	2.3939	3.4717
ILLITE	4.6112	7.1155	5.4914	7.0709
MONTMORI	5.2388	7.0213	5.9941	7.0239
CHLORITE	-10.2035	-1.5399	-10.3782	-2.6262
CHLORT-M	1.0166	8.9292	1.1029	8.9182
CHLORT-F	28.8931	36.0350	27.9278	37.7586
NA2SO3	-21.1867	-21.5167	-22.5699	-22.2061
K2SO3	-25.0198	-25.0431	-26.0936	-25.6981
CASO3.2H	-10.0685	-10.7854	-11.8578	-11.5392
CASO3.5H	-10.4336	-11.1546	-12.2304	-11.9119
MGSO3	-20.5718	-21.2041	-22.3068	-21.9838
BASO3	-12.5639	-13.1140	-14.1540	-13.8289
CH4(GAS)	-12.5193	-15.5382	-18.8421	-17.6115
CO2(GAS)	-0.3787	-0.7010	0.3440	-0.0676
O2(GAS)	-66.3828	-65.1683	-63.1287	-63.9496

MAKELA - ARUMATOR #2 COMPARISON

SOURCE	ARUM-2-HOMO	ARUM-2-TOP	ARUM-2-MID	ARUM-2-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
ELEMENTS	TOTAL MOLALITIES OF ELEMENTS			
AL	5.206E-05	2.621E-05	1.043E-04	9.319E-05
BA	6.575E-07	4.414E-07	1.464E-06	1.465E-06
TOT.ALK.	1.123E-02	2.536E-02	2.588E-02	2.894E-02
CA	1.682E-02	1.076E-02	2.000E-02	2.635E-02
CD	3.571E-07	1.798E-07	2.684E-07	1.790E-07
CL	1.981E-03	1.995E-03	1.985E-03	1.986E-03
CU	6.316E-07	3.180E-07	4.747E-07	3.165E-07
FE	1.779E-04	1.086E-05	1.008E-03	3.242E-05
K	2.823E-03	2.481E-03	6.660E-03	9.079E-03
MG	6.562E-03	5.528E-03	1.257E-02	1.746E-02
MN	1.425E-04	1.030E-04	3.112E-04	5.126E-04
NA	4.582E-03	4.747E-03	1.023E-02	1.387E-02
NI	1.880E-05	3.442E-06	8.564E-06	1.199E-05
PB	1.453E-06	4.877E-07	9.706E-07	1.456E-06
S	1.665E-02	8.607E-02	2.550E-02	2.039E-02
SI	2.839E-04	2.355E-04	4.520E-04	5.190E-04
SR	2.176E-05	2.076E-05	4.017E-05	5.395E-05
ZN	6.139E-07	3.091E-07	3.076E-07	3.077E-07
PARAMETERS	DESCRIPTION OF SOLUTIONS			
pH	5.61	6.74	6.72	6.30
pE	-1.1873	-1.2116	-1.6337	-0.5771
H2O Activity	0.9983	0.9977	0.9983	0.9978
Ionic Strength	0.0642	0.1828	0.0977	0.1128
Temperature, C	24.0	22.2	23.0	23.8
Electr.Balance	8.486E-03	-1.594E-01	5.927E-03	4.011E-02
THOR	-1.506E+01	-1.563E+01	-4.273E+01	-3.451E+00
T.Alkalinity	1.123E-02	2.536E-02	2.588E-02	2.894E-02
Iterations	19	14	17	17
Total Carbon	5.696E-02	3.282E-02	3.362E-02	5.054E-02
MINERALS	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)
ALOH3(A)	0.4311	0.6668	1.3042	1.2621
ALOHSO4	0.5099	-0.6958	-0.6542	-0.0829
AL4(OH)1	7.2133	7.0786	8.8700	9.1538
ALUM K	-8.1938	-9.9482	-9.9823	-9.0483
ALUNITE	9.7425	8.6904	9.8264	10.5778
ANHYDRIT	-0.0133	0.1201	0.0917	0.0751
ARAGONIT	-0.7444	0.1518	0.6874	0.4587
ARTINITE	-10.5662	-7.7955	-6.5620	-7.3923
BARITE	1.0608	1.4883	1.4876	1.2836
BOEHMITE	2.2292	2.4603	3.0996	3.0599
BRUCITE	-8.2876	-6.5530	-5.9251	-6.5148
CALCITE	-0.6027	0.2990	0.8321	0.6010
CELESTIT	-0.9462	-0.3963	-0.6175	-0.6802
CHALCEDO	-0.0075	-0.0561	0.2088	0.2619
CHRYSOTI	-13.6983	-8.5204	-6.1385	-7.9229
CLINOENS	-6.3614	-4.6696	-3.7794	-4.3484
CRISTOBA	0.0647	0.0201	0.2833	0.3345

MAKELA - ARUMATOR #2 COMPARISON

SOURCE	ARUM-2-HOMO	ARUM-2-TOP	ARUM-2-MID	ARUM-2-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
DIASPORE	3.9478	4.1946	4.8269	4.7802
DIOPSIDE	-9.5260	-6.2452	-4.5508	-5.7242
DOLOMITE	-1.5510	0.3740	1.5181	1.0829
EPSOMITE	-2.8901	-2.5914	-2.5606	-2.5717
SEPIOLIT	-12.2656	-8.7728	-6.7974	-7.9533
FERRIHYD	-6.5426	-4.7620	-2.9954	-4.6500
FE3(OH)8	-16.5551	-12.2739	-6.5524	-12.1724
FEOH)2.7	-1.1371	0.2912	2.0720	0.5415
FES PPT	-4.2682	-13.6858	-8.6235	-15.4788
FE2(SO4)	-47.8249	-49.2165	-47.1902	-48.3807
FORSTERI	-14.8249	-11.4102	-9.8869	-11.0701
GIBBSITE	2.0516	2.3064	2.9352	2.8847
GOETHITE	-2.1876	-0.4716	1.3236	-0.3020
GREENALI	-6.9468	-4.9250	2.1883	-4.6197
GREIGITE	-11.9681	-48.2375	-31.0204	-54.8183
GYPSUM	0.2051	0.3561	0.3202	0.2951
HALITE	-6.8251	-6.9181	-6.5083	-6.3862
HEMATITE	0.6209	4.0446	7.6386	4.3914
HUNTITE	-7.5425	-3.5960	-1.2190	-2.0510
HYDRMAGN	-20.6324	-14.8176	-11.7398	-13.1710
JAROSITE	-20.2012	-18.2323	-13.9053	-17.4257
MACKINAW	-3.5382	-12.9558	-7.8935	-14.7488
MAGADIIT	-7.3076	-6.7159	-4.4317	-4.2869
MAGHEMIT	-9.6930	-6.1310	-2.5987	-5.9072
MAGNESIT	-1.4444	-0.4222	0.1892	-0.0144
MAGNETIT	-0.1867	3.8695	9.6908	4.1719
MELANTER	-4.1460	-4.9775	-3.3348	-4.9857
MIRABILI	-6.1131	-5.4388	-5.2876	-5.2395
NATRON	-10.3485	-8.9266	-8.2046	-8.3618
NESQUEHO	-3.8557	-2.8325	-2.2212	-2.4261
PHLOGOPI	-37.6054	-31.3062	-27.5226	-29.5602
PYRITE	3.9954	-13.2984	-6.2684	-16.4179
QUARTZ	0.4864	0.4451	0.7068	0.7566
SIDERITE	-0.5083	-0.6128	1.6090	-0.2360
SIO2(A,G	-0.8154	-0.8688	-0.6017	-0.5465
SIO2(A,P	-0.8154	-0.8688	-0.6017	-0.5465
STRONTIA	-2.5941	-1.2831	-0.9395	-1.2135
TALC	-11.6022	-6.4842	-3.5892	-5.2837
THENARDI	-7.0840	-6.4948	-6.3070	-6.2180
THERMONA	-11.8275	-10.4865	-9.7297	-9.8482
TREMOLIT	-24.3568	-12.6640	-6.3861	-10.4333
WITHERIT	-4.7712	-3.6081	-3.0326	-3.4366
PYROLUSI	-25.8061	-22.0545	-22.1437	-21.3682
BIRNESSI	-27.9642	-24.0818	-24.2293	-23.5117
NSUTITE	-27.3742	-23.4918	-23.6393	-22.9217
BIXBYITE	-28.0106	-22.5252	-21.9058	-21.7135
HAUSMANN	-32.3288	-25.1168	-23.7857	-24.1734
PYROCROI	-8.2917	-6.6065	-5.8762	-6.4381
MANGANIT	-14.0569	-11.2802	-10.9856	-10.9046
RHODOCHR	-0.7664	0.2101	0.9222	0.7748
MNCL2, 4	-12.6462	-13.1316	-12.3850	-12.2003
MNS GREE	-12.1285	-20.5057	-16.9350	-22.0748
MNSO4	-9.4521	-9.2977	-9.1232	-9.0323
MN2(SO4)	-63.7654	-63.0755	-64.0327	-61.7924
CU METAL	3.4463	3.2535	3.8120	2.5445

MAKELA - ARUMATOR #2 COMPARISON

SOURCE DATE	ARUM-2-HOMO 07/07/90	ARUM-2-TOP 08/08/90	ARUM-2-MID 08/08/90	ARUM-2-BOT 08/08/90
NANTOKIT	-2.5644	-2.8582	-2.6797	-2.8830
CUPRITE	-0.3019	1.3981	1.6872	0.4809
CHALCOCI	17.7055	9.4608	12.5379	6.7012
DJURLEIT	17.1751	8.9421	11.9828	6.2303
ANILITE	15.6111	7.4096	10.3493	4.8318
BLAUBLEI	9.5058	1.2891	3.9284	-0.7030
COVELLIT	8.7030	0.6217	3.1534	-1.4027
CU2SO4	-13.5272	-13.4385	-13.6692	-14.1872
CUPROUSF	6.3255	8.9255	10.8500	8.6064
MELANOTH	-19.8184	-20.2737	-20.4482	-19.5606
CUCO3	-7.6233	-6.4751	-6.7466	-6.2552
CU(OH)2	-7.9056	-6.0252	-6.2890	-6.2226
ATACAMIT	-14.2571	-11.6178	-12.1213	-11.5985
ANTLERIT	-19.5718	-15.2883	-16.7127	-15.9374
BROCHANT	-25.8498	-19.6175	-21.3362	-20.5248
LANGITE	-27.3983	-21.3438	-22.9830	-22.0930
TENORITE	-6.8848	-5.0041	-5.2682	-5.2016
CUOCUSO4	-23.6709	-21.4953	-22.5546	-21.7444
CUSO4	-15.8807	-15.5759	-16.3755	-15.6363
CHALCANT	-10.1860	-9.7948	-10.6323	-9.9330
DIOPTASE	-9.2890	-7.4496	-7.4518	-7.3357
CUPRICFE	-8.5057	-3.1681	0.1471	-3.0483
CHALCOPY	12.7731	-4.6744	2.8967	-8.5376
ZN METAL	-30.2237	-31.1606	-29.8949	-31.8358
ZNCL2	-19.4322	-20.4205	-19.9820	-19.8615
SMITHSON	-3.5651	-2.9464	-2.6065	-2.8837
ZNCO3, 1	-3.2951	-2.6570	-2.3256	-2.6118
ZN(OH)2	-7.0290	-5.5902	-5.2818	-6.0230
ZN2(OH)3	-14.6731	-12.9698	-12.3054	-13.3744
ZN5(OH)8	-32.9753	-28.1298	-26.4925	-29.3717
ZN2(OH)2	-12.1560	-10.8410	-10.7657	-11.5812
ZN4(OH)6	-24.1141	-19.9214	-19.2293	-21.5271
ZNO(ACTI	-6.8383	-5.3992	-5.0910	-5.8320
ZINCITE	-6.7222	-5.3811	-5.0292	-5.7268
ZN3O(SO4	-32.9552	-32.0416	-32.0759	-32.8420
ZNS (A)	-1.6382	-10.3206	-7.1456	-12.4386
SPHALERI	0.9431	-7.7188	-4.5529	-9.8550
WURTZITE	-1.0048	-9.6810	-6.5087	-11.8045
ZNSIO3	-2.0423	-0.7543	-0.1354	-0.7780
WILLEMIT	-10.0078	-7.3484	-6.3912	-7.7447
ZINCOSIT	-12.1843	-12.3942	-12.5890	-12.6250
ZNSO4, 1	-8.5840	-8.7557	-8.9674	-9.0206
BIANCHIT	-7.3718	-7.4978	-7.7292	-7.8043
GOSLARIT	-7.1640	-7.2748	-7.5128	-7.5950
CD METAL	-18.6132	-19.1694	-17.8027	-20.0070
GAMMA CD	-18.7136	-19.2703	-17.9034	-20.1074
OTAVITE	-0.5216	0.4106	0.8815	0.3706
CDCL2	-12.3960	-13.0293	-12.4784	-12.6098
CDCL2, 1	-11.3602	-11.9819	-11.4360	-11.5729
CDCL2,2.	-11.1226	-11.7289	-11.1896	-11.3338
CD(OH)2	-9.8849	-8.1495	-7.7025	-8.6698
CDOHCL	-8.1882	-7.6604	-7.1511	-7.6901
CD3(OH)4	-24.8627	-21.2190	-20.4197	-22.6546
CD3OH2(S	-22.6106	-20.5296	-20.2720	-21.8398
CD4(OH)6	-26.9376	-21.5585	-20.3122	-23.5144

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MAKELA - ARUMATOR #2 COMPARISON

SOURCE DATE	ARUM-2-HOMO 07/07/90	ARUM-2-TOP 08/08/90	ARUM-2-MID 08/08/90	ARUM-2-BOT 08/08/90
MONTEPON	-11.4152	-9.7905	-9.2943	-10.2122
CDSIO3	-8.8741	-7.2822	-6.5281	-7.3999
CDSO4	-9.7692	-9.6625	-9.7277	-9.9986
CDSO4, 1	-8.1921	-8.0533	-8.1327	-8.4182
CDSO4,2.	-7.9754	-7.8226	-7.9080	-8.2002
GREENOCK	4.5672	-3.7617	-0.4735	-6.0178
PB METAL	-8.9106	-10.2104	-9.0062	-10.6820
COTUNNIT	-7.8440	-9.2582	-8.8530	-8.4394
PHOSGENI	-6.6408	-7.9713	-7.2109	-6.7331
CERRUSIT	-0.6810	-0.5504	-0.2161	-0.1727
MASSICOT	-8.7484	-7.9139	-7.5593	-7.9280
LITHARGE	-8.5574	-7.7212	-7.3674	-7.7368
PBO, .3H	-8.7772	-7.8677	-7.5465	-7.9486
PB2OCO3	-9.1482	-8.1812	-7.4932	-7.8193
LARNAKIT	-4.9285	-4.7010	-4.5874	-4.7118
PB3O2SO4	-11.4408	-10.3678	-9.9045	-10.4025
PB4O3SO4	-18.9731	-17.0546	-16.2417	-17.1132
PB3O2CO3	-16.5021	-14.6925	-13.6535	-14.3520
PBSIO3	-6.6787	-5.8798	-5.2661	-5.5875
PB2SIO4	-14.9570	-13.3235	-12.3552	-13.0454
ANGLESIT	-1.6004	-2.2440	-2.4686	-2.2080
GALENA	4.2119	-4.9294	-1.7730	-6.7582
PLATTNER	-36.4268	-33.6230	-34.0445	-33.0329
PB2O3	-43.7893	-39.7589	-40.0007	-39.5317
MINIUM	-52.4897	-48.0103	-47.7256	-47.4544
PB(OH)2	-3.9822	-3.1355	-2.7863	-3.1607
LAURIONI	-4.8328	-5.0977	-4.7289	-4.7176
PB2(OH)3	-8.8005	-8.1561	-7.4659	-7.8569
HYDCERRU	-5.9837	-4.8567	-3.8473	-4.1434
PB2O(OH)	-17.7947	-15.9757	-15.3333	-16.1375
PB4(OH)6	-17.8888	-15.8139	-15.0703	-16.0122
NICO3	-5.4733	-5.6724	-5.2293	-5.1577
NI(OH)2	-4.9884	-4.2059	-3.8662	-4.3303
NI4(OH)6	-22.6520	-21.6306	-20.5700	-21.5170
BUNSENIT	-6.7718	-6.2327	-5.7846	-6.1404
MILLERIT	-1.3856	-10.8660	-7.5966	-12.5495
RETGERSI	-5.8232	-6.7364	-6.8782	-6.6180
MORENOSI	-5.4994	-6.4046	-6.5498	-6.2935
NI2SIO4	-6.6867	-5.6129	-4.4715	-5.1496
ANALCIME	0.1921	1.3857	2.9268	2.7114
HALLOYSI	5.5905	5.9883	7.7823	7.7942
KAOLINIT	8.8615	9.2792	11.0643	11.0674
LEONHARD	16.4080	20.3258	26.0339	24.9356
LOW ALBI	0.7973	1.9464	3.7505	3.5866
ANALBITE	-0.1291	1.0083	2.8177	2.6589
MUSCOVIT	11.8286	13.4116	16.5787	16.3091
ANNITE	0.6975	3.6979	12.2765	5.2786
ANORTHIT	-1.9696	0.0032	2.3640	1.7468
PYROPHYL	9.2015	9.6391	11.9017	11.9592
LAUMONTI	1.9694	3.8934	6.7631	6.2293
WAIRAKIT	-2.4704	-0.6029	2.2917	1.7836
MALACHIT	-11.3397	-8.3128	-8.8474	-8.2889
AZURITE	-16.8731	-12.7346	-13.5244	-12.4583
SULFUR	-4.2247	-12.1703	-10.1717	-13.4350
LIME	-23.9595	-22.4536	-21.8556	-22.4547

MAKELA - ARUMATOR #2 COMPARISON

SOURCE	ARUM-2-HOMO	ARUM-2-TOP	ARUM-2-MID	ARUM-2-BOT
DATE	07/07/90	08/08/90	08/08/90	08/08/90
PORTLAND	-13.7918	-12.2164	-11.6493	-12.2795
WUSTITE	-4.6717	-3.9838	-1.9088	-3.9801
PERICLAS	-13.0323	-11.3435	-10.6953	-11.2943
HERCYNIT	1.3854	2.4692	5.9797	3.6338
SPINEL	-6.2251	-4.0590	-2.1391	-2.8239
MAG-FERR	-11.6706	-6.5565	-2.3150	-6.1619
WOLLASTO	-7.6324	-6.0758	-5.2571	-5.8472
P-WOLLST	-8.4862	-6.9367	-6.1149	-6.7019
CA-OLIVI	-23.4145	-20.3025	-18.9080	-20.1191
LARNITE	-24.9108	-21.8102	-20.4106	-21.6167
CA3SIO5	-50.8073	-46.2135	-44.2103	-46.0097
MONTICEL	-16.4093	-13.1362	-11.6817	-12.8831
AKERMINI	-28.2602	-23.4642	-21.1760	-22.9526
MERWINIT	-40.4513	-34.0795	-31.2245	-33.6311
KALSILIT	-2.6256	-1.4824	-0.0903	-0.3536
LEUCITE	0.2724	1.3770	3.0296	2.8149
MICROCLI	2.5575	3.6368	5.5439	5.3721
H SANIDI	2.1128	3.1833	5.0943	4.9263
NEPHELIN	-3.7938	-2.5771	-1.2897	-1.5466
GEHLENIT	-20.9782	-17.4268	-14.7438	-16.0238
LEPIDOCR	-3.0219	-1.2410	0.5253	-1.1291
NA-NONTR	2.8440	6.6252	11.4763	8.2687
K-NONTRO	3.8206	7.5712	12.4598	9.2528
CA-NONTR	9.6660	13.3744	18.1888	14.9627
MG-NONTR	9.3020	13.0331	17.8592	14.6364
FE(OH)3S	-4.3226	-2.5420	-0.7754	-2.4300
PREHNITE	-4.7728	-1.1894	1.9661	0.7345
PHILLIPS	1.3683	2.5488	4.3750	4.1774
ILLITE	4.3009	5.7107	8.5410	8.2975
MONTMORI	5.1463	5.7978	8.3442	8.3276
CHLORITE	-13.1340	-4.0401	1.1262	-1.9382
CHLORT-M	-1.8911	6.0576	11.9231	7.8530
CHLORT-F	27.0671	32.1499	41.2169	34.1072
NA2SO3	-21.0645	-22.6972	-21.6207	-22.7999
K2SO3	-24.7673	-26.5817	-25.2804	-26.4570
CASO3.2H	-10.0027	-12.0503	-11.2079	-12.5115
CASO3.5H	-10.3501	-12.4128	-11.5638	-12.8603
MGSO3	-20.4219	-22.4278	-21.4724	-22.7128
BASO3	-12.3985	-14.1906	-13.3035	-14.7769
CH4(GAS)	-12.1757	-21.5482	-18.1109	-22.8694
CO2(GAS)	0.1353	-0.6632	-0.6413	-0.1872
O2(GAS)	-65.7677	-61.9578	-63.4526	-60.6350

MAKELA - ARUMATOR #3 COMPARISON

SOURCE	ARUM-3-TOP	ARUM-3-MID	ARUM-3-BOT	ARUM-3-TOP	ARUM-3-MID	ARUM-3-BOT
DATE	07/07/90	07/07/90	07/07/90	08/08/90	08/08/90	08/08/90
ELEMENTS	TOTAL MOLALITIES OF ELEMENTS					
AL	3.352E-05	5.590E-05	4.099E-05	2.235E-05	2.609E-05	2.238E-05
BA	7.316E-07	7.321E-07	7.321E-07	7.318E-07	7.323E-07	7.329E-07
TOT.ALK.	2.008E-05	2.009E-05	4.962E-03	6.025E-03	6.753E-03	1.529E-02
CA	1.848E-02	2.039E-02	2.067E-02	1.630E-02	1.804E-02	1.783E-02
CD	1.788E-06	1.789E-06	1.789E-06	8.942E-07	8.948E-07	1.791E-06
CL	1.984E-03	1.985E-03	1.985E-03	1.985E-03	1.986E-03	1.987E-03
CU	4.744E-07	6.329E-07	1.266E-06	6.327E-07	6.331E-07	7.920E-07
FE	3.706E-03	4.015E-03	4.933E-03	3.617E-03	3.692E-03	8.723E-03
K	4.523E-03	5.194E-03	4.654E-03	4.755E-03	5.530E-03	5.560E-03
MG	1.021E-02	1.166E-02	1.059E-02	9.881E-03	1.138E-02	1.126E-02
MN	5.121E-04	5.673E-04	5.490E-04	4.574E-04	5.309E-04	5.680E-04
NA	6.075E-03	6.954E-03	5.992E-03	6.383E-03	7.393E-03	7.399E-03
NI	2.687E-03	3.100E-03	2.740E-03	1.609E-03	1.816E-03	2.555E-03
PB	2.425E-06	2.912E-06	3.397E-06	1.940E-06	1.942E-06	2.915E-06
S	3.102E-02	3.560E-02	3.327E-02	3.263E-02	3.705E-02	3.789E-02
SI	3.345E-04	3.347E-04	4.184E-04	4.016E-04	3.851E-04	4.021E-04
SR	3.211E-05	3.557E-05	3.328E-05	3.556E-05	3.788E-05	3.791E-05
ZN	4.304E-05	6.306E-05	3.538E-05	1.384E-05	2.000E-05	1.386E-05
PARAMETERS	DESCRIPTION OF SOLUTIONS					
pH, units	4.44	4.49	4.72	4.93	5.02	5.27
pE	0.8252	1.4957	0.4642	2.4028	1.6504	1.9190
H2O Activity	0.9988	0.9987	0.9962	0.9968	0.9969	0.9963
Ionic Strength	0.0907	0.1010	0.0995	0.0909	0.1010	0.1122
Temperature, C	20.0	20.0	21.0	20.5	20.0	21.0
Electr.Balance	1.806E-02	1.887E-02	1.642E-02	1.786E-03	1.212E-03	1.969E-03
THOR	4.968E-02	1.949E-01	4.653E-01	6.841E-01	6.494E-01	7.980E-01
T.Alkalinity	2.008E-05	2.009E-05	4.962E-03	6.025E-03	6.752E-03	1.529E-02
Iterations	18	19	23	20	23	20
Total Carbon	1.163E-03	1.015E-03	1.495E-01	1.210E-01	1.103E-01	1.410E-01
MINERALS	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)	Log(IAP/KT)
ALOH3(A)	-3.2149	-2.8887	-2.2607	-1.9635	-1.7104	-1.0279
ALOHSO4	-0.3188	-0.0546	0.0191	-0.0312	0.1113	0.2081
AL4(OH)1	-3.7390	-2.4961	-0.7443	0.1998	1.2046	3.1431
ALUM K	-7.3861	-7.0808	-7.3414	-7.5389	-7.3825	-7.5766
ALUNITE	3.7653	4.7237	5.6031	6.0612	6.7881	7.8332
ANHYDRIT	0.1278	0.1880	0.1804	0.1026	0.1576	0.1358
ARAGONIT	-4.8098	-4.7467	-2.0887	-1.8933	-1.7459	-1.1481
ARTINITE	-16.9314	-16.7137	-13.6259	-13.0069	-12.6506	-11.5061
BARITE	1.3357	1.3605	1.3179	1.3762	1.4066	1.3598
BOEHMITE	-1.4279	-1.1016	-0.4699	-0.1743	0.0775	0.7629
BRUCITE	-10.7541	-10.6156	-10.1314	-9.7823	-9.5923	-9.0422
CALCITE	-4.6555	-4.5923	-1.9377	-1.7407	-1.5916	-0.9971
CELESTIT	-0.6163	-0.5474	-0.6018	-0.5231	-0.4740	-0.5038
CHALCEDO	0.1121	0.1136	0.2008	0.1874	0.1760	0.1848
CHRYSOTI	-20.6997	-20.2814	-18.6934	-17.6533	-17.0858	-15.4579
CLINOENS	-8.6962	-8.5562	-7.9868	-7.6499	-7.4697	-6.9137

MAKELA - ARUMATOR #3 COMPARISON

SOURCE DATE	ARUM-3-TOP 07/07/90	ARUM-3-MID 07/07/90	ARUM-3-BOT 07/07/90	ARUM-3-TOP 08/08/90	ARUM-3-MID 08/08/90	ARUM-3-BOT 08/08/90
CRISTOBA	0.1933	0.1947	0.2797	0.2674	0.2571	0.2636
DIASPORE	0.3259	0.6522	1.2750	1.5751	1.8312	2.5078
DIOPSIDE	-14.2775	-14.0139	-12.8449	-12.2343	-11.8822	-10.7886
DOLOMITE	-9.5347	-9.3922	-4.1224	-3.6603	-3.3493	-2.1512
EPSOMITE	-2.5214	-2.4454	-2.5270	-2.5216	-2.4400	-2.4815
SEPIOLIT	-16.4593	-16.1782	-15.0456	-14.3395	-13.9454	-12.9153
FERRIHYD	-6.8957	-6.0611	-6.2844	-3.8651	-4.3696	-2.9590
FE3(OH)8	-18.3569	-16.5734	-16.4661	-11.3445	-12.1830	-8.4946
FEOH)2.7	-1.1436	-0.3253	-0.6171	1.7404	1.2076	2.5420
FES PPT	-8.9553	-14.6668	-8.3347	-25.5471	-20.1461	-24.0964
FE2(SO4)	-41.4869	-40.0036	-41.7575	-38.1388	-39.6578	-38.2380
FORSTERI	-19.6530	-19.3745	-18.3131	-17.6307	-17.2638	-16.1508
GIBBSITE	-1.5518	-1.2255	-0.6084	-0.3058	-0.0473	0.6244
GOETHITE	-2.6862	-1.8516	-2.0371	0.3636	-0.1593	1.2883
GREENALI	-10.0867	-9.7412	-7.8805	-7.0701	-6.5929	-3.9507
GREIGITE	-28.1364	-49.6559	-26.4358	-91.2959	-71.2126	-86.7934
GYPSUM	0.3872	0.4473	0.4273	0.3551	0.4152	0.3827
HALITE	-6.7214	-6.6721	-6.7380	-6.7032	-6.6473	-6.6579
HEMATITE	-0.3956	1.2738	0.9086	5.7074	4.6591	7.5595
HUNTITE	-23.4423	-23.1410	-12.6279	-11.6421	-11.0137	-8.5955
HYDRMAGN	-38.8440	-38.3882	-27.4435	-26.0353	-25.1994	-22.2319
JAROSITE	-16.7219	-14.3421	-15.8458	-9.4206	-11.2941	-7.9570
MACKINAW	-8.2253	-13.9368	-7.6047	-24.8171	-19.4161	-23.3664
MAGADIIT	-7.8539	-7.7403	-6.8874	-6.7818	-6.7532	-6.3647
MAGHEMIT	-10.4000	-8.7305	-9.1739	-4.3361	-5.3452	-2.5230
MAGNESIT	-5.3767	-5.2973	-2.6822	-2.4171	-2.2551	-1.6516
MAGNETIT	-2.4957	-0.7120	-0.4725	4.5842	3.6817	7.4990
MELANTER	-2.6653	-2.6135	-2.5600	-2.6533	-2.6239	-2.2831
MIRABILI	-5.4967	-5.3516	-5.5664	-5.4428	-5.2651	-5.3407
NATRON	-13.9738	-13.8258	-11.3658	-10.9736	-10.7080	-10.1548
NESQUEHO	-7.7835	-7.7043	-5.0933	-4.8270	-4.6645	-4.0627
PHLOGOPI	-49.2332	-48.3833	-45.8654	-44.3345	-43.3903	-40.7938
PYRITE	-2.4845	-12.5809	-2.1044	-32.5002	-23.1791	-30.9387
QUARTZ	0.6223	0.6237	0.7068	0.6955	0.6861	0.6908
SIDERITE	-3.3206	-3.2655	-0.5172	-0.3498	-0.2391	0.7448
SIO2(A,G	-0.7065	-0.7051	-0.6152	-0.6299	-0.6427	-0.6312
SIO2(A,P	-0.7065	-0.7051	-0.6152	-0.6299	-0.6427	-0.6312
STRONTIA	-6.4755	-6.4036	-3.7910	-3.4398	-3.2991	-2.7078
TALC	-18.2817	-17.8605	-16.1179	-15.0944	-14.5392	-12.9144
THENARDI	-6.6662	-6.5205	-6.6750	-6.5787	-6.4260	-6.4494
THERMONA	-15.6410	-15.4924	-12.9759	-12.6094	-12.3676	-11.7651
TREMOLIT	-40.5097	-39.5612	-35.4881	-33.2398	-31.9766	-28.1721
WITHERIT	-8.7647	-8.7371	-6.0982	-5.7746	-5.6597	-5.0710
PYROLUSI	-26.5093	-24.9445	-25.9651	-21.4018	-22.5710	-20.8832
BIRNESSI	-28.3745	-26.8097	-27.9042	-23.3040	-24.4362	-22.8224
NSUTITE	-27.7845	-26.2197	-27.3142	-22.7140	-23.8462	-22.2324
BIXBYITE	-30.6694	-28.9808	-29.5271	-24.6435	-25.6023	-23.3730
HAUSMANN	-36.9590	-35.1466	-35.2147	-30.0127	-30.7631	-27.9884
PYROCROI	-10.3552	-10.2315	-9.7310	-9.4240	-9.2273	-8.6588
MANGANIT	-15.3097	-14.4654	-14.7584	-12.3068	-12.7766	-11.6814
RHODOCHR	-4.2874	-4.2227	-1.5934	-1.3694	-1.1997	-0.5798
MNCL2, 4	-11.9964	-11.9821	-12.0439	-12.0968	-12.0383	-12.0809
MNS GREE	-17.6151	-23.3171	-17.0810	-34.2482	-28.7997	-33.0910
MNSO4	-8.8985	-8.8367	-8.8400	-8.9056	-8.8449	-8.8115
MN2(SO4)	-59.0251	-57.5226	-59.4688	-55.7596	-57.1836	-56.4461

MAKELA - ARUMATOR #3 COMPARISON

SOURCE DATE	ARUM-3-TOP 07/07/90	ARUM-3-MID 07/07/90	ARUM-3-BOT 07/07/90	ARUM-3-TOP 08/08/90	ARUM-3-MID 08/08/90	ARUM-3-BOT 08/08/90
CU METAL	1.4716	0.8892	2.2198	-0.3836	0.6757	0.3194
NANTOKIT	-2.6125	-2.5291	-2.2113	-2.8806	-2.5873	-2.6615
CUPRITE	-2.8471	-2.5711	-1.4429	-2.3877	-1.6295	-1.2341
CHALCOCI	12.0014	6.4517	13.2477	-5.1378	0.9056	-3.6257
DJURLEIT	11.5991	6.0878	12.7966	-5.4173	0.5559	-3.9514
ANILITE	10.3895	4.9854	11.4516	-6.2844	-0.5073	-4.9467
BLAUBLEI	5.2533	0.2278	5.9085	-10.1750	-5.1261	-9.2546
COVELLIT	4.9078	-0.0595	5.4225	-10.3678	-5.3920	-9.5505
CU2SO4	-13.6348	-13.4208	-12.7520	-14.0919	-13.4924	-13.5869
CUPROUSF	4.6299	5.6027	5.9626	7.9003	7.7661	9.3925
MELANOTH	-18.0754	-17.3261	-17.9869	-16.7393	-17.2290	-16.9869
CUCO3	-9.7311	-8.9317	-6.9862	-5.4204	-5.7586	-4.9355
CU(OH)2	-8.5032	-7.6447	-7.8413	-6.1859	-6.4904	-5.7321
ATACAMIT	-14.1781	-12.5158	-13.1674	-10.0474	-10.7358	-9.5035
ANTLERIT	-18.3597	-15.8463	-17.0379	-12.3954	-13.3958	-11.7539
BROCHANT	-25.0822	-21.7103	-23.1372	-16.8201	-18.1056	-15.7440
LANGITE	-27.0279	-23.6561	-24.9836	-18.7164	-20.0522	-17.5905
TENORITE	-7.4825	-6.6240	-6.8196	-5.1645	-5.4689	-4.7104
CUOCUSO4	-22.3714	-20.7165	-21.5815	-18.6590	-19.4195	-18.4068
CUSO4	-13.9614	-13.1649	-13.8400	-12.5699	-13.0230	-12.7745
CHALCANT	-8.0692	-7.2730	-8.0030	-6.7069	-7.1351	-6.9375
DIOPTASE	-9.7500	-8.8901	-9.0038	-7.3597	-7.6734	-6.9106
CUPRICFE	-10.0456	-7.5177	-8.0972	-1.6340	-2.9773	0.6628
CHALCOPY	4.4059	-6.2729	5.5121	-27.4761	-17.0847	-25.2225
ZN METAL	-32.8701	-34.0710	-32.1536	-36.4956	-34.9022	-35.5072
ZNCL2	-17.8882	-17.7574	-17.9509	-18.3822	-18.2780	-18.4041
SMITHSON	-5.8639	-5.6830	-3.2722	-3.3843	-3.1275	-2.6747
ZNCO3, 1	-5.5499	-5.3691	-2.9704	-3.0767	-2.8144	-2.3729
ZN(OH)2	-7.6209	-7.3809	-7.1619	-7.1596	-6.8443	-6.5058
ZN2(OH)3	-14.7011	-14.2758	-14.0662	-14.2673	-13.7311	-13.3087
ZN5(OH)8	-33.6231	-32.5326	-31.8942	-32.2942	-30.9065	-29.7232
ZN2(OH)2	-10.7938	-10.3759	-10.4236	-10.8007	-10.3150	-10.1553
ZN4(OH)6	-23.9356	-23.0377	-22.6474	-23.0199	-21.9035	-21.0670
ZNO(ACTI	-7.4304	-7.1903	-6.9703	-6.9682	-6.6529	-6.3142
ZINCITE	-7.5336	-7.2936	-7.0181	-7.0438	-6.7562	-6.3621
ZN3O(SO4	-30.2614	-29.6655	-29.8216	-30.6568	-30.0795	-29.9411
ZNS (A)	-5.7849	-11.3706	-5.3828	-22.8712	-17.3208	-21.8090
SPHALERI	-3.1576	-8.7434	-2.7671	-20.2498	-14.6935	-19.1933
WURTZITE	-5.1375	-10.7233	-4.7389	-22.2256	-16.6734	-21.1651
ZNSIO3	-2.7442	-2.5028	-2.1375	-2.1778	-1.9030	-1.4975
WILLEMIT	-11.4534	-10.9719	-10.3483	-10.4057	-9.8346	-9.0522
ZINCOSIT	-10.4230	-10.2450	-10.4631	-10.8667	-10.7208	-10.8508
ZNSO4, 1	-6.7365	-6.5586	-6.7994	-7.1920	-7.0351	-7.1871
BIANCHIT	-5.4180	-5.2404	-5.5131	-5.8912	-5.7209	-5.9008
GOSLARIT	-5.1753	-4.9977	-5.2803	-5.6537	-5.4790	-5.6679
CD METAL	-21.8107	-23.1791	-21.0928	-25.3156	-23.8614	-24.1029
GAMMA CD	-21.9124	-23.2808	-21.1942	-25.4172	-23.9632	-24.2043
OTAVITE	-3.5221	-3.5087	-0.8908	-0.9028	-0.8043	0.0501
CDCL2	-11.4610	-11.4977	-11.5075	-11.8271	-11.8694	-11.6173
CDCL2, 1	-10.3984	-10.4351	-10.4528	-10.7687	-10.8076	-10.5625
CDCL2,2.	-10.1250	-10.1618	-10.1900	-10.5011	-10.5355	-10.2997
CD(OH)2	-11.2163	-11.1438	-10.7082	-10.6106	-10.4583	-9.7087
CDOHCL	-8.4383	-8.4204	-8.1945	-8.3120	-8.2635	-7.7496
CD3(OH)4	-26.3109	-26.1555	-25.3345	-25.4233	-25.1114	-23.3798
CD3OH2(S	-21.5130	-21.4196	-21.0843	-21.5548	-21.3879	-20.1735

MAKELA - ARUMATOR #3 COMPARISON

SOURCE DATE	ARUM-3-TOP 07/07/90	ARUM-3-MID 07/07/90	ARUM-3-BOT 07/07/90	ARUM-3-TOP 08/08/90	ARUM-3-MID 08/08/90	ARUM-3-BOT 08/08/90
CD4(OH)6	-29.7172	-29.4892	-28.2327	-28.2239	-27.7598	-25.2786
MONTEPON	-12.9953	-12.9228	-12.4234	-12.3573	-12.2365	-11.4239
CDSIO3	-10.2991	-10.2252	-9.6475	-9.5904	-9.4765	-8.6641
CDSO4	-8.7027	-8.6922	-8.7049	-9.0076	-9.0191	-8.7493
CDSO4, 1	-7.0529	-7.0425	-7.0746	-7.3679	-7.3702	-7.1189
CDSO4,2.	-6.8035	-6.7932	-6.8353	-7.1241	-7.1222	-6.8795
GREENOCK	-0.1916	-5.9449	0.2274	-17.1497	-11.7462	-15.8554
PB METAL	-12.3578	-13.6497	-11.6577	-15.8280	-14.3578	-14.8933
COTUNNIT	-7.2422	-7.2025	-7.2855	-7.5630	-7.5999	-7.6207
PHOSGENI	-9.5241	-9.3946	-6.8948	-7.1613	-7.1133	-6.5145
CERRUSIT	-4.0612	-3.9713	-1.4150	-1.3908	-1.2927	-0.6995
MASSICOT	-10.6826	-10.5337	-10.1022	-9.9967	-9.8731	-9.3282
LITHARGE	-10.4876	-10.3387	-9.9082	-9.8023	-9.6781	-9.1342
PBO, .3H	-10.5430	-10.3941	-10.0055	-9.8787	-9.7338	-9.2315
PB2OCO3	-14.4581	-14.2193	-11.2326	-11.1024	-10.8801	-9.7431
LARNAKIT	-5.9789	-5.7430	-5.4356	-5.5717	-5.4350	-4.9313
PB3O2SO4	-14.4006	-14.0158	-13.2831	-13.3108	-13.0473	-12.0048
PB4O3SO4	-23.8425	-23.3087	-22.1508	-22.0699	-21.6796	-20.0985
PB3O2CO3	-23.7281	-23.3403	-19.9268	-19.6888	-19.3406	-17.6632
PBSIO3	-8.4641	-8.3137	-7.8024	-7.7067	-7.5908	-7.0444
PB2SIO4	-18.6763	-18.3769	-17.4342	-17.2330	-16.9934	-15.9022
ANGLESIT	-0.7986	-0.7117	-0.8150	-1.0670	-1.0643	-1.0847
GALENA	-0.9507	-6.6276	-0.5107	-17.8546	-12.4546	-16.8189
PLATTNER	-37.2172	-35.6273	-36.6632	-32.3285	-33.5981	-31.8795
PB2O3	-45.6358	-43.8970	-44.7232	-40.1723	-41.2072	-39.1655
MINIUM	-57.1334	-55.2455	-55.4223	-50.8748	-51.8952	-49.0906
PB(OH)2	-5.8883	-5.7394	-5.3160	-5.2068	-5.0796	-4.5420
LAURIONI	-5.4428	-5.3485	-5.1890	-5.2678	-5.2173	-4.9695
PB2(OH)3	-11.1762	-10.9330	-10.3856	-10.3374	-10.1420	-9.3921
HYDCERRU	-14.6072	-14.2787	-8.7534	-8.5904	-8.2617	-6.5484
PB2O(OH)	-21.3262	-21.0284	-20.2516	-19.9979	-19.7080	-18.7035
PB4(OH)6	-22.4056	-21.8720	-20.8062	-20.6801	-20.2453	-18.7538
NICO3	-7.2476	-7.1659	-4.6070	-4.5613	-4.4198	-3.7504
NI(OH)2	-4.6941	-4.5533	-4.2776	-4.0719	-3.8261	-3.3625
NI4(OH)6	-20.1514	-19.6500	-18.7243	-18.4371	-17.7534	-16.1075
BUNSENIT	-7.0233	-6.8824	-6.4679	-6.3312	-6.1544	-5.5528
MILLERIT	-4.9634	-10.6483	-4.5236	-21.8487	-16.4079	-20.6907
RETGERSI	-3.2762	-3.1977	-3.3398	-3.5513	-3.4876	-3.4683
MORENOSI	-2.9337	-2.8553	-3.0031	-3.2120	-3.1460	-3.1316
NI2SIO4	-6.9712	-6.6879	-5.7966	-5.5242	-5.1694	-3.9824
ANALCIME	-4.3262	-3.8932	-2.9122	-2.4091	-2.0359	-1.0768
HALLOYSI	-1.4106	-0.7552	0.6631	1.2370	1.7269	3.0966
AOLINITE	1.9050	2.5604	3.9674	4.5469	5.0425	6.4010
LEONHARD	-2.0933	-0.5325	3.6507	5.3314	6.6445	10.4520
LOW ALBI	-3.5932	-3.1587	-2.0915	-1.6010	-1.2382	-0.2721
ANALBITE	-4.5457	-4.1112	-3.0374	-2.5502	-2.1907	-1.2180
MUSCOVIT	0.3443	1.4312	3.7433	4.8259	5.7107	8.0129
ANNITE	-7.3883	-6.6112	-3.7400	-2.4791	-1.6656	2.0260
ANORTHIT	-11.6487	-10.8709	-8.9025	-8.0599	-7.4045	-5.4699
PYROPHYL	2.7456	3.4039	4.9204	5.5058	6.0117	7.3219
LAUMONTI	-7.3590	-6.5787	-4.4679	-3.6373	-2.9906	-1.0673
WAIRAKIT	-11.9268	-11.1463	-9.0012	-8.1871	-7.5566	-5.6006
MALACHIT	-14.0487	-12.3909	-10.6411	-7.4204	-8.0635	-6.4812
AZURITE	-21.7718	-19.3146	-15.5986	-10.8224	-11.8141	-9.3880
SULFUR	-6.1730	-10.5578	-6.3742	-19.5772	-15.6768	-19.4468

MAKELA - ARUMATOR #3 COMPARISON

SOURCE	ARUM-3-TOP	ARUM-3-MID	ARUM-3-BOT	ARUM-3-TOP	ARUM-3-MID	ARUM-3-BOT
DATE	07/07/90	07/07/90	07/07/90	08/08/90	08/08/90	08/08/90
LIME	-26.7908	-26.6685	-26.0817	-25.8318	-25.6858	-25.0825
PORTLAND	-16.4666	-16.3444	-15.7981	-15.5283	-15.3625	-14.7990
WUSTITE	-5.8694	-5.6848	-5.1813	-4.7171	-4.6574	-3.7181
PERICLAS	-15.6022	-15.4637	-14.9523	-14.6165	-14.4396	-13.8632
HERCYNIT	-7.2464	-6.4795	-4.6040	-3.7582	-3.1123	-0.8179
SPINEL	-16.0762	-15.2850	-13.5175	-12.5866	-11.9020	-9.9628
MAG-FERR	-15.2536	-13.4456	-13.3003	-8.1654	-9.0362	-5.5603
WOLLASTO	-10.1217	-9.9980	-9.3801	-9.1157	-8.9529	-8.3970
P-WOLLST	-10.9913	-10.8677	-10.2457	-9.9833	-9.8225	-9.2626
CA-OLIVI	-28.6241	-28.3782	-27.2014	-26.6732	-26.3503	-25.2192
LARNITE	-30.1460	-29.9000	-28.7168	-28.1918	-27.8722	-26.7346
CA3SIO5	-58.9021	-58.5339	-56.7567	-55.9854	-55.5234	-53.7753
MONTICEL	-21.4063	-21.1441	-20.0305	-19.4225	-19.0748	-17.9583
AKERMINI	-35.8220	-35.4361	-33.6856	-32.8226	-32.3217	-30.6302
MERWINIT	-50.6879	-50.1797	-47.8818	-46.7493	-46.0826	-43.8273
KALSILIT	-7.2020	-6.7705	-5.8542	-5.3570	-4.9740	-4.0181
LEUCITE	-4.1620	-3.7291	-2.7312	-2.2446	-1.8701	-0.9111
MICROCLI	-1.7054	-1.2710	-0.1990	0.2808	0.6504	1.6051
H SANIDI	-2.1696	-1.7353	-0.6583	-0.1810	0.1861	1.1458
NEPHELIN	-8.4897	-8.0581	-7.1487	-6.6396	-6.2624	-5.2972
GEHLENIT	-33.5541	-32.6555	-30.2011	-29.0885	-28.2688	-25.7533
LEPIDOCR	-3.3752	-2.5405	-2.7628	-0.3438	-0.8483	0.5627
NA-NONTR	0.9428	2.7594	2.9176	7.8731	6.9449	10.1259
K-NONTRO	1.9446	3.7612	3.9253	8.8752	7.9470	11.1286
CA-NONTR	7.7245	9.5270	9.7081	14.6356	13.6919	16.8719
MG-NONTR	7.3868	9.1920	9.3649	14.3045	13.3638	16.5435
FE(OH)3S	-4.6757	-3.8411	-4.0644	-1.6451	-2.1496	-0.7390
PREHNITE	-16.8194	-15.9180	-13.3634	-12.2408	-11.4073	-8.9477
PHILLIPS	-2.8091	-2.3747	-1.3438	-0.8396	-0.4546	0.4679
ILLITE	-4.8464	-3.9941	-2.0177	-1.1578	-0.4748	1.4055
MONTMORI	-3.3345	-2.5482	-0.6778	0.0149	0.5952	2.3057
CHLORITE	-32.1896	-30.8403	-26.9507	-24.6256	-23.1767	-19.0873
CHLORT-M	-18.2390	-16.7238	-13.3386	-10.5885	-9.1745	-5.1428
CHLORT-F	11.9928	13.5053	17.3232	19.7039	21.1344	25.9744
NA2SO3	-22.3560	-23.6512	-22.1956	-26.3998	-24.9254	-25.9796
K2SO3	-25.8979	-27.1934	-25.7043	-29.9418	-28.4657	-29.5189
CASO3.2H	-11.4779	-12.8587	-11.2817	-15.6478	-14.2593	-15.3359
CASO3.5H	-11.8602	-13.2410	-11.6536	-16.0245	-14.6404	-15.7078
MGSO3	-21.9532	-23.3177	-21.7339	-26.0546	-24.6753	-25.6982
BASO3	-13.8277	-15.2439	-13.6776	-17.9192	-16.5663	-17.6453
CH4(GAS)	-19.9671	-25.7901	-17.3508	-34.5716	-29.2480	-33.4478
CO2(GAS)	-1.5224	-1.5816	0.5968	0.4889	0.4365	0.5383
O2(GAS)	-63.7683	-60.8864	-63.7483	-55.3262	-58.1492	-55.7291

Summary of LOG(IAP/KT) signs from PHREEQE output for metal sulfides, sulfates, carbonates, and (hydr)oxides.

SAMPLE	JUL		AUG		ARUM-1				ARUM-2				ARUM-3					
SOURCES	S	F	S	BP	H	T	M	B	H	T	M	B	T	M	B	T	M	B
Al(OH)3	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-
AlOHSO4	-	-	-	+	+	-	+	-	+	-	-	-	-	-	+	-	+	+
Alunite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Al4(OH)10	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-	+	+	+
Anhydrite	-	+	-	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+
Aragonite	-	-	-	-	-	+	-	-	-	+	+	+	-	-	-	-	-	-
Barite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Boehmite	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	+	+
Calcite	-	+	+	+	-	+	+	+	-	+	+	+	-	-	-	-	-	-
Chalcedone	+	+	-	+	-	+	+	+	-	-	+	+	+	+	+	+	+	+
Cristobalite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Diaspore	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
Dolomite	-	-	-	-	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Ferrihydroxide	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe3(OH)8	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe(OH)2.7	+	+	+	+	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Gibbsite	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Goethite	+	+	+	+	-	-	-	+	-	-	+	-	-	-	-	+	-	+
Gypsum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Hematite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Jarosite	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maghemite	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnesite	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-
Magnesioferrite	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnetite	+	+	+	+	+	+	-	+	-	+	+	+	-	-	-	+	+	+
Pyrite	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Quartz	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Siderite	-	-	-	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-
Rhodochrosite	-	-	-	-	-	+	-	+	-	+	+	+	-	-	-	-	-	-
Cu metal	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Cuprite	-	-	-	-	+	+	+	+	-	+	+	+	-	-	-	-	-	-
Chalcosite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Djurleite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	-
Anilite	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-
Blaublei	-	-	-	-	+	+	+	+	+	+	+	-	+	+	+	-	-	-
Covellite	-	-	-	-	+	+	+	+	+	+	+	-	+	-	+	-	-	-
Cupricferrite	+	+	+	+	-	-	-	-	-	-	+	-	-	-	-	-	-	+
Cuprousferrite	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chalcopyrite	-	-	-	-	+	+	+	+	+	-	+	-	+	-	+	-	-	-
Sphalerite	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Otavite	-	-	-	-	-	+	+	+	-	+	+	+	-	-	-	-	-	-
Greenockite	-	-	-	-	+	+	-	-	+	-	-	-	-	-	+	-	-	-
Galena	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-

S- Seepage; F- Feed water; BP-End of by-pass channel.
H- Homogenized; T- Top; M- Middle; B- Bottom.

1990 DENISON ARUM WATER DATA									
SAMPLE DATE	07/09/90	07/09/90	07/09/90	08/21/90	10/19/90	10/19/90	08/21/90	08/21/90	10/19/90
SAMPLE VOLUME					100	100			100
ASSAYERS CODE	1876	1877	1878	2073	2320/2359	2321/2360	2071	2072	2318/2357
SAMPLING LOCATION	SED.W#1	SED.W#2	TREATMENT	ST.E SURF.	ST.A-SURF.	ST.A-BOT.	WR.SURF.	WR.BOT.	WR.SURF.
PROCESSING CODE	FA	FA	FA	FA	FA	FA	FA	FA	FA
Field T C	22.0	21.5	20.0	27.8	7.0	7.0	27.8	22.4	11.0
Field pH	3.54	3.66	3.05	2.23	2.52	2.55	2.30	6.12	2.43
Field Cond(umhos)	1610	1820	3250	3300	1420	2420	4100	8800	1650
Field Potential(mV)	295	287	325	435	412	378	431	-203	434
Field Acidity				2310	230	500	3080	11090	115
Field Alkalinity								460	
Lab T C					9	9			9
Lab pH					2.80	2.70			2.86
Lab Cond(umhos)					1500	1900			1750
Lab Potential(mV)					400	350			360
Lab Alkalinity					10	10			10
Lab Acidity					1200	1100			900
ELEMENTS (mg/L) AT.WGHT									
Ag 107.8680		0.01	0.01						
Al 26.9815	5.3	12	1.3	62	37	74	73	0.7	37
As 74.9216			0.01	0.01			0.02	0.01	
B 10.8100				0.9	0.5	1.2	1.3	6.1	0.5
Ba 137.3300	0.08	0.06	0.01	0.01	0.01	0.01	0.01	0.05	0.01
Be 9.0122								0.02	
Bi 208.9804				0.02			0.02	0.1	0.01
Ca 40.0800	208	359	692	236	118	196	278	445	116
Cd 112.4100	0.07	0.04	0.05	0.08	0.04	0.1	0.1	0.5	0.03
Ce 140.1200				0.02	0.01	0.01	0.2	0.03	
Co 58.9332	0.3	1.1	0.09	0.9	0.4	0.9	1.1	0.7	0.4
Cr 51.9960	0.06	0.07	0.08	0.1	0.05	0.1	0.1	0.3	0.04
Cu 63.5460	0.04	0.04	0.05	0.2	0.1	0.5	0.4	0.09	0.2
Fe 55.8470	346	101	205	464	259	612	685	2544	256
K 39.0983	23	13	17	2.5	1.6	1.9	4.1	302	
La 138.9055	0.2	2.2	0.1	1.3	0.6	1.1	1.4	0.1	0.6
Mg 24.3050	36	76	158	50	25	39	60	113	24
Mn 54.9380	15	46	19	7.2	3.5	4.8	8.4	19	3.1
Mo 95.9400				0.01			0.01	0.04	
Na 22.9898	14	23	73	18	9.1	12	22	45	8.9
Nb 92.9064	0.02	0.04	0.03	0.02	0.1	0.02	0.03	0.1	
Ni 58.7000	0.6	0.4	0.1	0.5	0.2	0.5	0.6	0.8	0.2
P 30.9738	0.9	0.7	0.9	1.7	0.8	1.8	2.4	9.1	0.8
Pb 207.2000	1.1	0.8	0.3	0.3	0.1	0.4	0.4	1.6	0.1
S 32.0600	456	492	905	952	552	1165	1187	2604	531
Sb 121.7500				0.01			0.1	0.05	
Se 78.9600				0.01			0.1	0.4	
Si 28.0855	22	15	11	13	8.8	15	18	14	9.6
Sn 118.6900				0.01			0.02	0.08	
Sr 87.6200	0.7	1.5	1.5	0.9	0.4	0.7	1.1	1.9	0.4
Te 127.6000	0.03	0.03	0.03	0.04			0.06	0.2	0.01
Th 232.0381				0.01		0.01	0.01	0.02	0.01
Ti 47.9000	0.01	0.09	0.02	0.01	0.01	0.04	0.02	0.01	0.02
U 238.0290	0.02	0.02	0.03	0.04	0.03	0.06	0.06	0.1	0.02
V 50.9415	0.01	0.01	0.01	0.04	0.02	0.06	0.06	0.05	0.01
W 183.8500				0.03			0.04	0.07	0.01
Y 88.9059	0.07	0.5	0.03	2.4	1.2	2.4	2.9	0.4	1.2
Zn 65.3800	0.8	1.2	0.2	2.1	1.2	2.2	2.8	0.8	1.3
Zr 91.2200	0.05	0.08	0.06	0.1	0.08	0.2	0.2	0.2	0.08

1990 DENISON ARUM WATER DATA										
SAMPLE DATE		07/09/90	07/09/90	07/09/90	08/21/90	10/19/90	10/19/90	08/21/90	08/21/90	10/19/90
SAMPLE VOLUME						100	100			100
ASSAYERS CODE		1876	1877	1878	2073	2320/2359	2321/2360	2071	2072	2318/2357
SAMPLING LOCATION		SED.W#1	SED.W#2	TREATMENT	ST.E SURF.	ST.A-SURF.	ST.A-BOT.	WR.SURF.	WR.BOT.	WR.SURF.
PROCESSING CODE		FA	FA	FA	FA	FA	FA	FA	FA	FA
Chloride	35.4530	50	53	84		9.8	10.2			11.7
Sulphate	96.06									
Carbonate	61.01									
Bicarbonate	60.01	0	0	0	0	0	0	0	561.2	0
Nitrate		12.6	3.5	22.4						
Ammonium										
Fluoride		0.6	1.3	1.2						
SUM of CATIONS		31.48	34.19	60.22	54.77	29.59	57.72	70.19	178.64	29.88
SUM of ANIONS		29.86	32.19	58.83	59.39	34.71	72.96	74.05	171.80	33.46
RATIO		1.05	1.06	1.02	0.92	0.85	0.79	0.95	1.04	0.89
ERROR%		2.64%	3.02%	1.17%	-4.04%	-7.96%	-11.66%	-2.68%	1.95%	-5.64%
Fe valency		2.5	3	2	3	3	3	3	3	3
Fe minus S		-11.13	-14.44	-26.39	-25.54	-14.90	-30.86	-30.89	-58.45	-14.27
SUM of METALS minus S		-10.82	-13.55	-26.04	-25.32	-14.79	-30.69	-30.63	-58.05	-14.17
S, millimole/L		14.22	15.35	28.23	29.69	17.22	36.34	37.02	81.22	16.56
pH		3.54	3.66	3.05	2.23	2.52	2.55	2.30	6.12	2.43
Eh		538	530	569	674	665	631	670	40	684
pE		9.09	8.96	9.62	11.39	11.23	10.66	11.32	0.67	11.56
Labels			SED.		E		A		W-AUG	
Labels		W1	W2	TR	S	S	B	S	B	S
Labels	W1	W2	TR	ES	AS	AB	WS	WB	WS	

SAMPLE DATE	10/19/90	07/09/90	07/09/90	07/09/90	08/21/90	08/21/90	10/19/90	10/19/90	10/19/90	07/09/90
SAMPLE VOLUME	100						100	100	100	
ASSAYERS CODE	2319/2358	1865	1864	1863	2074	2075	2312/2351	2313/2352	2314/2353	1868
SAMPLING LOCATION	WR.BOT.	A-TOP	A-MID	A-BOT	A-SHORT	A-LONG	A-TOP	A-MID	A-BOT	B-TOP
PROCESSING CODE	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Field T C	10.0	8.0	21.0	20.0	27.9	25.4	12.0	10.0	9.0	20.5
Field pH	5.68	5.05	4.86	4.54	5.89	4.86	5.55	6.27	5.78	5.15
Field Cond(umhos)	5100	1380	1500	1580	700	1020	550	540	540	940
Field Potential(mV	-100	-261	-215	-176	-197	-159	-103	-111	-88	-215
Field Acidity	1220	650	1050	1342	225	560	30	40	80	617
Field Alkalinity	410	190	131		330	85	225	300	210	274
Lab T C	9	10.7	8.7	8.7			10	9	9	9.7
Lab pH	5.85	5.06	5.10	4.74			5.85	6.45	5.89	5.51
Lab Cond(umhos)	4100						700	580	600	
Lab Potential(mV)	-55	59	25	123			-50	-90	-100	-30
Lab Alkalinity	300	148	210	95			450	400	410	390
Lab Acidity	3210	885	1135	1420			340	200	190	730
ELEMENTS (mg/L)										
Ag										
Al	3.7	2.7	3.8	7.2	0.9	6.2	0.6	0.5	0.6	1.4
As				0.01						
B	4.7				0.1	0.2	0.3	0.2	0.2	
Ba	0.05	0.04	0.05	0.05	0.03	0.03	0.02	0.01	0.02	0.02
Be	0.01									
Bi										
Ca	342	166	197	207	102	126	92	91	89	106
Cd	0.4	0.05	0.06	0.08		0.02	0.01	0.01	0.01	0.2
Ce										
Co	0.7	0.1	0.2	0.3		0.1	0.01	0.01		0.01
Cr	0.2	0.1	0.2	0.2	0.1	0.1	0.09	0.08	0.08	0.1
Cu	0.07	0.01	0.02	0.02		0.01				
Fe	2978	325	422	425	78	148	106	84	92	158
K	221	49	53	52	47	38	40	43	39	43
La	0.3	0.07	0.1	0.1	0.01	0.1				0.01
Mg	100	15	17	19	11	12	10	11	10	12
Mn	14	3.3	4.1	4.1	2.4	2.4	2.5	2.2	2.3	3.1
Mo										
Na	37	12	12	11	11	8.7	10	10	10	8.5
Nb		0.01	0.025	0.02		0.01				
Ni	0.6	0.3	0.9	2.3	0.03	0.1	0.01	0.01	0.02	0.06
P	6.2	3.3	6.4	6.1	2.1	1.4	1.5	1.1	1.2	5.4
Pb	1.2	0.2	0.3	0.2	0.04	0.09	0.02	0.02	0.02	0.09
S	3090	250	303	325	4.1	166	3.6	22	6.8	9.4
Sb										
Se										
Si	11	11	12	12	13	10	10	9.2	9.5	10
Sn										
Sr	1.6	0.4	0.4	0.5	0.3	0.3	0.2	0.2	0.2	0.3
Te	0.01	0.02	0.03	0.03		0.01				0.01
Th	0.02						0.01	0.01	0.01	
Ti		0.02	0.06	0.06	0.01					0.02
U	0.01	0.02	0.02	0.03		0.01	0.01	0.01	0.01	0.01
V	0.03		0.01	0.01	0.01	0.02				
W										
Y	1.2	0.08	0.1	0.3	0.02	0.1	0.01	0.01	0.01	0.02
Zn	0.7	0.3	0.1	0.5	0.02	0.1	0.05	0.04	0.05	0.05
Zr	0.2	0.04	0.06	0.07	0.02	0.03			0.01	0.02

SAMPLE DATE	10/19/90	07/09/90	07/09/90	07/09/90	08/21/90	08/21/90	10/19/90	10/19/90	10/19/90	07/09/90
SAMPLE VOLUME	100						100	100	100	
ASSAYERS CODE	2319/2358	1865	1864	1863	2074	2075	2312/2351	2313/2352	2314/2353	1868
SAMPLING LOCATION	WR.BOT.	A-TOP	A-MID	A-BOT	A-SHORT	A-LONG	A-TOP	A-MID	A-BOT	B-TOP
PROCESSING CODE	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Chloride	69						9.7	8.5	4.8	
Sulphate										
Carbonate										
Bicarbonate	500.2	231.8	159.82	0	402.6	103.7	274.5	366	256.2	334.28
Nitrate										
Ammonium										
Fluoride										
SUM of CATIONS	193.47	23.37	28.81	29.92	10.66	14.72	10.83	10.13	10.14	13.68
SUM of ANIONS	203.05	19.46	21.57	20.27	6.96	12.08	5.07	7.71	4.83	6.16
RATIO	0.95	1.20	1.34	1.48	1.53	1.22	2.14	1.31	2.10	2.22
ERROR%	-2.41%	9.13%	14.38%	19.21%	20.96%	9.83%	36.21%	13.54%	35.50%	37.93%
Fe valency	3	2	2	2	2	2	2	2	2	2
Fe minus S	-69.72	-4.89	-5.67	-6.33	0.57	-3.85	0.84	0.07	0.61	1.12
SUM of METALS minu	-69.41	-4.81	-5.58	-6.20	0.62	-3.80	0.88	0.11	0.65	1.18
S, millimole/L	96.38	7.80	9.45	10.14	0.13	5.18	0.11	0.69	0.21	0.29
pH	5.68	5.05	4.86	4.54	5.89	4.86	5.55	6.27	5.78	5.15
Eh	151	-9	29	68	42	82	147	140	164	29
pE	2.55	-0.15	0.48	1.15	0.71	1.38	2.48	2.36	2.76	0.49
	W-OCT	A-JUL			A-AUG		A-OCT			
	B	T	M	B	SH	LG	T	M	B	T
	WB	AT	AM	AB	ASH	ALG	AT	AM	AB	BT

SAMPLE DATE	07/09/90	07/09/90	08/21/90	08/21/90	10/19/90	10/19/90	10/19/90	10/19/90	10/19/90	10/19/90
SAMPLE VOLUME					100	100	100	100	100	100
ASSAYERS CODE	1867	1866	2076	2077	2315/2354	2316/2355	2317/2356	2327	2329	2328
SAMPLING LOCATION	B-MID	B-BOT	B-SHORT	B-LONG	B-TOP	B-MID	B-BOT	DS-1	DS-21	DS-20
PROCESSING CODE	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Field T C	21.0	20.5	27.2	24.7	9.0	9.0	8.5			
Field pH	5.09	5.15	5.37	5.59	5.09	5.16	5.19			
Field Cond(umhos)	880		1290	880	905	840	680			
Field Potential(mV	-191	-201	-177	-184	-81	-88	-84			
Field Acidity	600	617	690	420	180	140	110			
Field Alkalinity	259	253	390	355	415	260	200			
Lab T C	9.7	11.5			10	10	9	10	11	9
Lab pH	5.39	5.39			5.41	5.69	5.71	6.65	5.59	5.41
Lab Cond(umhos)					800	850	800	2680	1178	5160
Lab Potential(mV)	42	-60			-90	-90	-95	-20	40	20
Lab Alkalinity	300	380			440	490	540	13		
Lab Acidity	700	700			650	580	590		227	946
ELEMENTS (mg/L)										
Ag										
Al	1.3	1.5	0.5	0.4	0.4	0.4	0.6	0.04	15	34
As										
B			0.4	0.2	0.5	0.5	0.4	0.06	0.07	0.5
Ba	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.01
Be										
Bi			0.01		0.01	0.01				
Ca	109	109	113	98	93	89	88	386	21	74
Cd	0.02	0.02	0.03	0.02	0.03	0.02	0.02			0.04
Ce									0.01	0.05
Co	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.1	0.5
Cr	0.1	0.1	0.1	0.08	0.07	0.07	0.07			0.07
Cu		0.01							0.03	0.5
Fe	160	163	247	14	267	259	172	0.09	43	297
K	50	45	46	43	37	35	36	9.2		
La	0.02	0.01	0.01	0.01					0.1	0.3
Mg	12	12	13	11	10	10	10	8.2	7.4	21
Mn	3.1	3.2	4.3	3.1	4.1	3.9	3.2	0.1	0.5	1.9
Mo										
Na	8.9	9.4	9.1	7.8	7.3	6.9	6.9	35	6.2	8.3
Nb			0.01							
Ni	0.08	0.1	0.07	0.05	0.04	0.05	0.04		0.07	0.4
P	5.4	6.1	2.4	1.7	1.2	1.8	2.5	0.03	0.1	0.9
Pb	0.07	0.06	0.1	0.09	0.09	0.1	0.08		0.04	0.1
S	15	10	5.7	4.4	4.5	4.3	5.3	336	133	545
Sb										
Se										
Si	11	11	16	12	12	12	10	0.3	6.1	9.9
Sn										
Sr	0.3	0.3	0.4	0.3	0.3	0.3	0.3	1.2	0.09	0.1
Te	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.02
Th					0.02	0.02	0.01			
Ti	0.02	0.02					0.01			0.08
U	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02		0.02
V			0.01	0.01						0.01
W										0.01
Y	0.02	0.02	0.08	0.04	0.07	0.07	0.07		0.1	0.5
Zn	0.03	0.08	0.08	0.04	0.07	0.07	0.07	0.01	0.4	2.2
Zr	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01		0.1

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SAMPLE DATE	07/09/90	07/09/90	08/21/90	08/21/90	10/19/90	10/19/90	10/19/90	10/19/90	10/19/90	10/19/90
SAMPLE VOLUME					100	100	100	100	100	100
ASSAYERS CODE	1867	1866	2076	2077	2315/2354	2316/2355	2317/2356	2327	2329	2328
SAMPLING LOCATION	B-MID	B-BOT	B-SHORT	B-LONG	B-TOP	B-MID	B-BOT	DS-1	DS-21	DS-20
PROCESSING CODE	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Chloride					19.5	15.8	7.3			
Sulphate										
Carbonate										
Bicarbonate	315.98	308.66	475.8	433.1	506.3	317.2	244			
Nitrate										
Ammonium										
Fluoride										
SUM of CATIONS	14.09	14.12	17.35	7.90	16.49	15.93	12.79	21.71	5.94	25.66
SUM of ANIONS	6.20	5.77	8.28	7.49	9.27	6.00	4.60	20.96	8.30	34.00
RATIO	2.27	2.45	2.09	1.05	1.78	2.66	2.78	1.04	0.72	0.75
ERROR%	38.87%	41.99%	35.35%	2.63%	28.05%	45.28%	47.06%	1.75%	-16.58%	-13.98%
Fe valency	2	2	2	2	2	2	2	2	3	3
Fe minus S	0.96	1.15	2.03	-0.01	2.25	2.18	1.37	-10.48	-3.76	-14.34
SUM of METALS minu	1.02	1.21	2.12	0.05	2.33	2.26	1.44	-10.48	-3.74	-14.25
S, millimole/L	0.47	0.31	0.18	0.14	0.14	0.13	0.17	10.48	4.15	17.00
pH	5.09	5.15	5.37	5.59	5.09	5.16	5.19	6.65	5.59	5.41
Eh	53	43	63	57	171	164	168	231	290	272
pE	0.89	0.73	1.06	0.97	2.88	2.76	2.84	3.90	4.90	4.59
	B-JUL			B-AUG		B-OCT		DS-OCT		
	M	B	SH	LG	T	M	B	1	21	20
	BM	BB	BSH	BLG	BT	BM	BB	1	21	20

SAMPLE DATE	10/19/90
SAMPLE VOLUME	100
ASSAYERS CODE	2330
SAMPLING LOCATION	DS-22
PROCESSING CODE	FA
Field T C	
Field pH	
Field Cond(umhos)	
Field Potential(mV	
Field Acidity	
Field Alkalinity	
Lab T C	9
Lab pH	5.40
Lab Cond(umhos)	5600
Lab Potential(mV)	-20
Lab Alkalinity	
Lab Acidity	619
ELEMENTS (mg/L)	
Ag	
Al	31
As	
B	0.8
Ba	0.02
Be	
Bi	0.02
Ca	123
Cd	0.06
Ce	0.08
Co	0.7
Cr	0.06
Cu	0.7
Fe	445
K	4.5
La	0.4
Mg	18
Mn	1.9
Mo	
Na	17
Nb	0.01
Ni	0.4
P	1.4
Pb	0.3
S	739
Sb	
Se	
Si	13
Sn	
Sr	0.3
Te	
Th	
Ti	0.4
U	0.03
V	0.03
W	0.02
Y	1.1
Zn	2.9
Zr	0.1

SAMPLE DATE	10/19/90
SAMPLE VOLUME	100
ASSAYERS CODE	2330
SAMPLING LOCATION	DS-22
PROCESSING CODE	FA
Chloride	
Sulphate	
Carbonate	
Bicarbonate	
Nitrate	
Ammonium	
Fluoride	
SUM of CATIONS	35.99
SUM of ANIONS	46.10
RATIO	0.78
ERROR%	-12.32%
Fe valency	3
Fe minus S	-19.07
SUM of METALS minu	-18.95
S, millimole/L	23.05
pH	5.40
Eh	232
pE	3.91
	22
	22

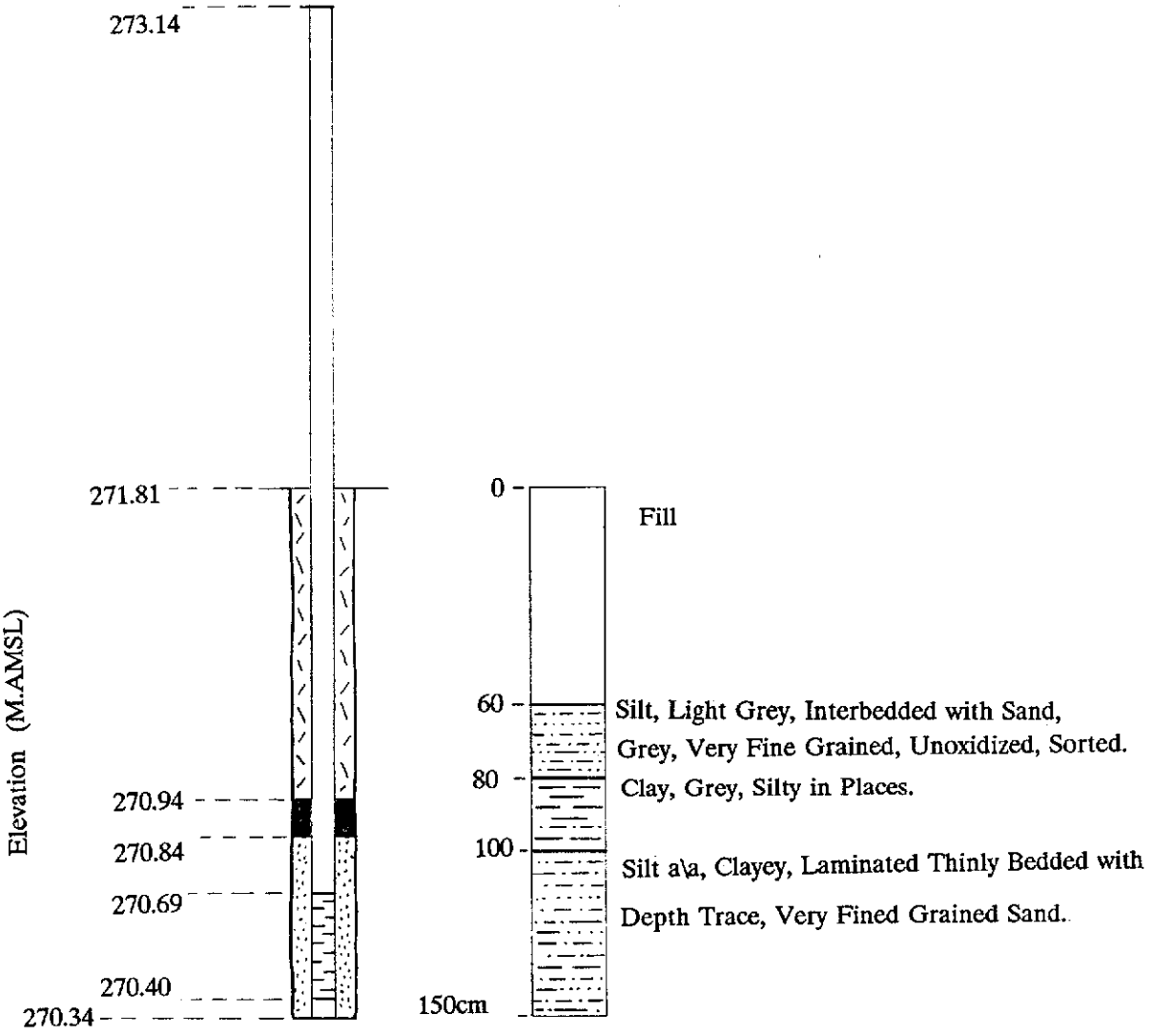


FIGURE 1: Stratigraphy and Completion Details of Piezometer: P-1

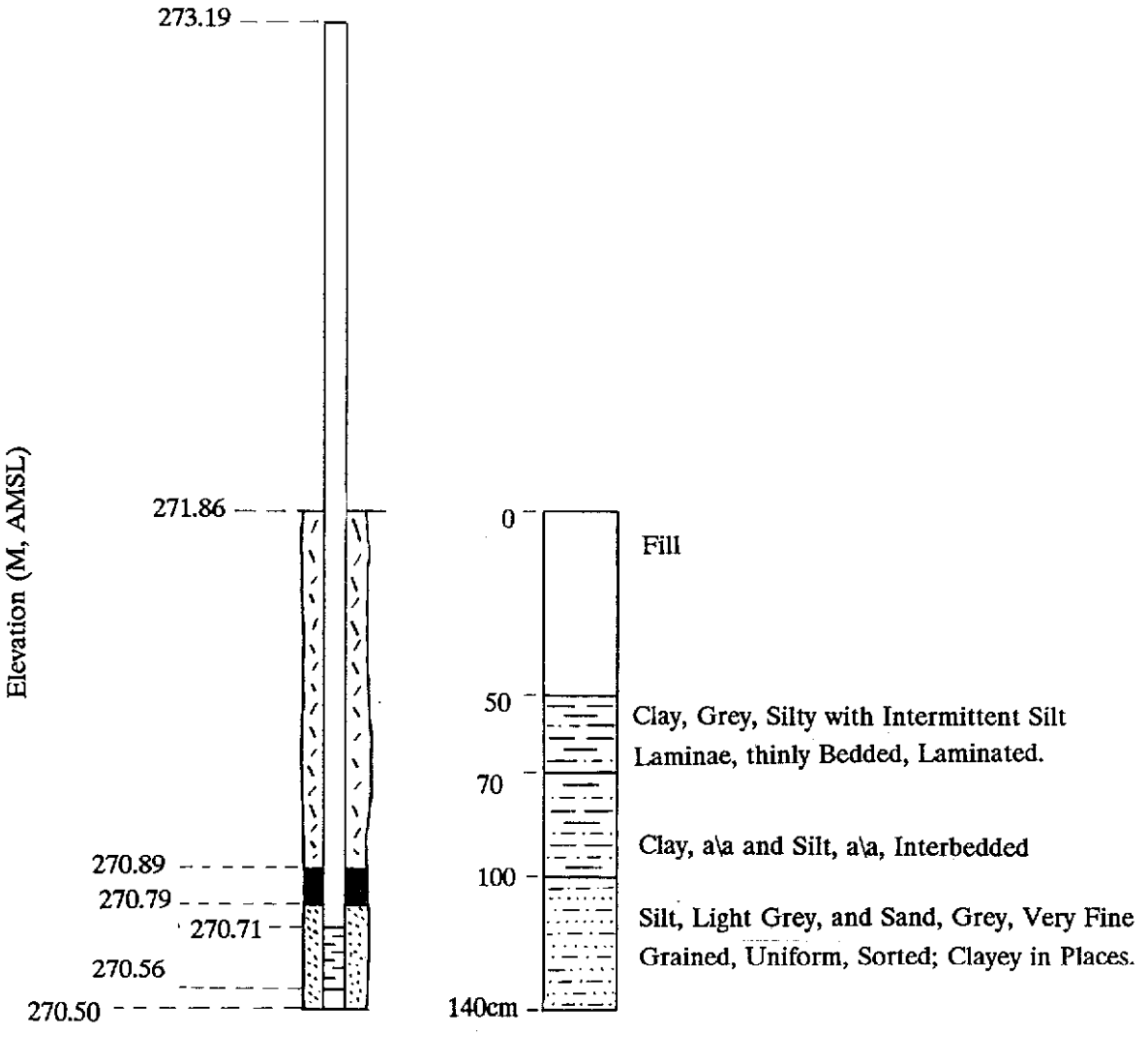


FIGURE 2: Stratigraphy and Completion Details of Piezometer: P-2

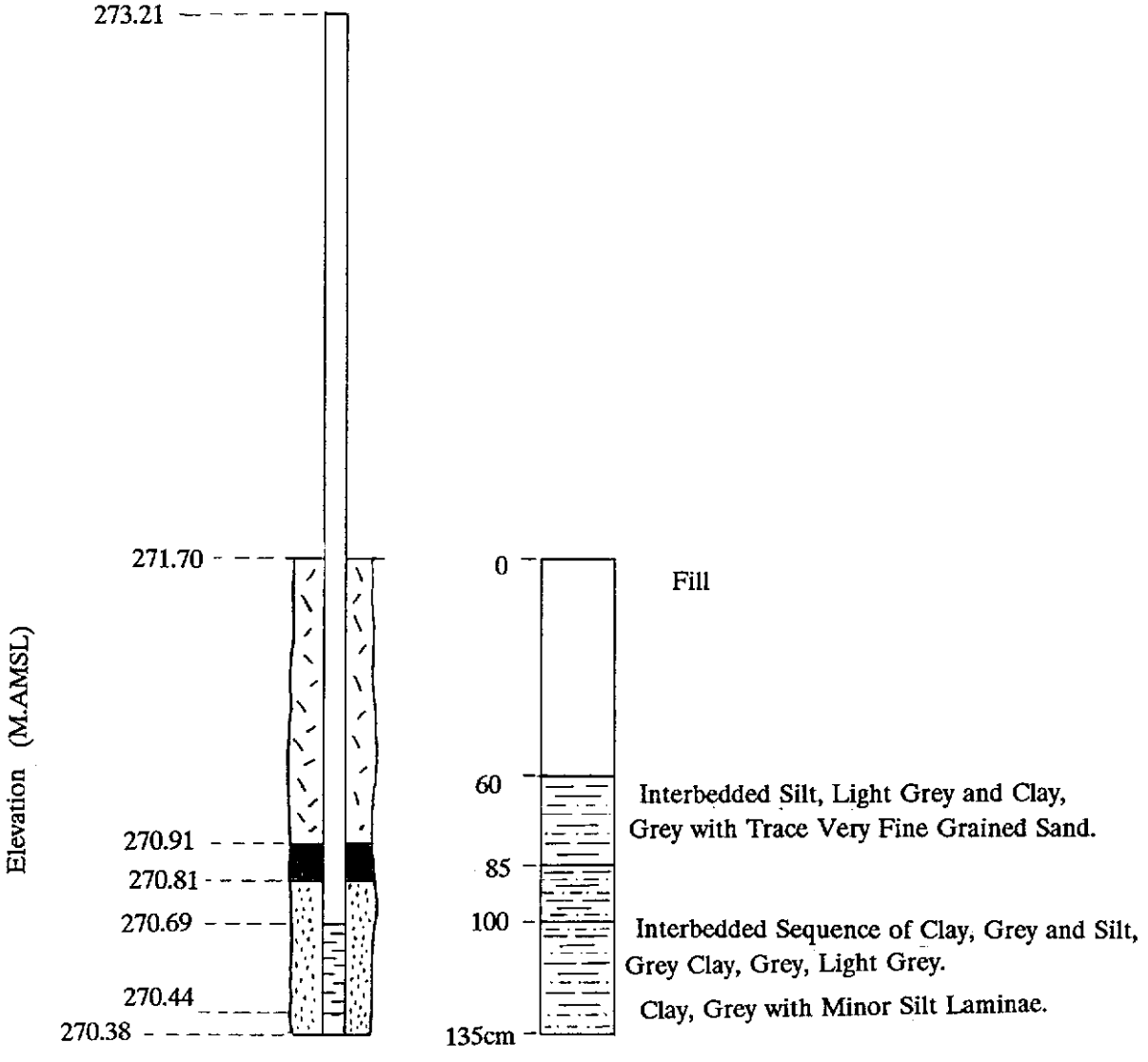


FIGURE 3: Stratigraphy and Completion Details of Piezometer: P-3

Figure 28: Stratigraphy and Completion of Piezometer:P-4

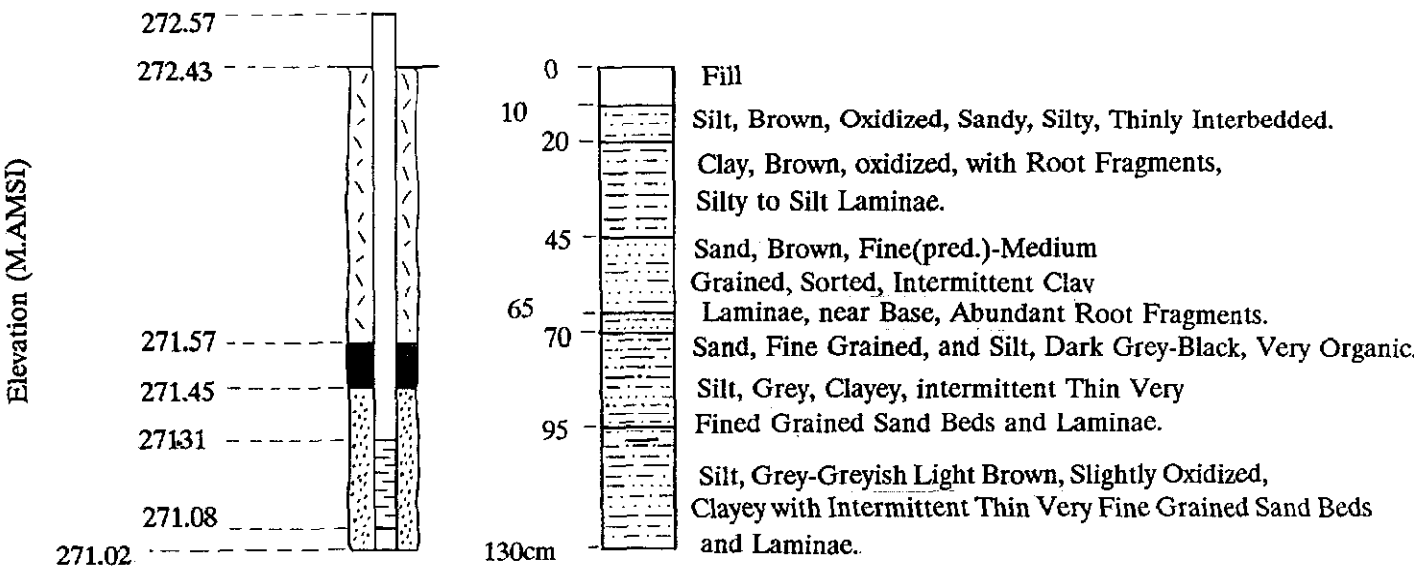


FIGURE 4: Stratigraphy and Completion Details of Piezometer: P-4

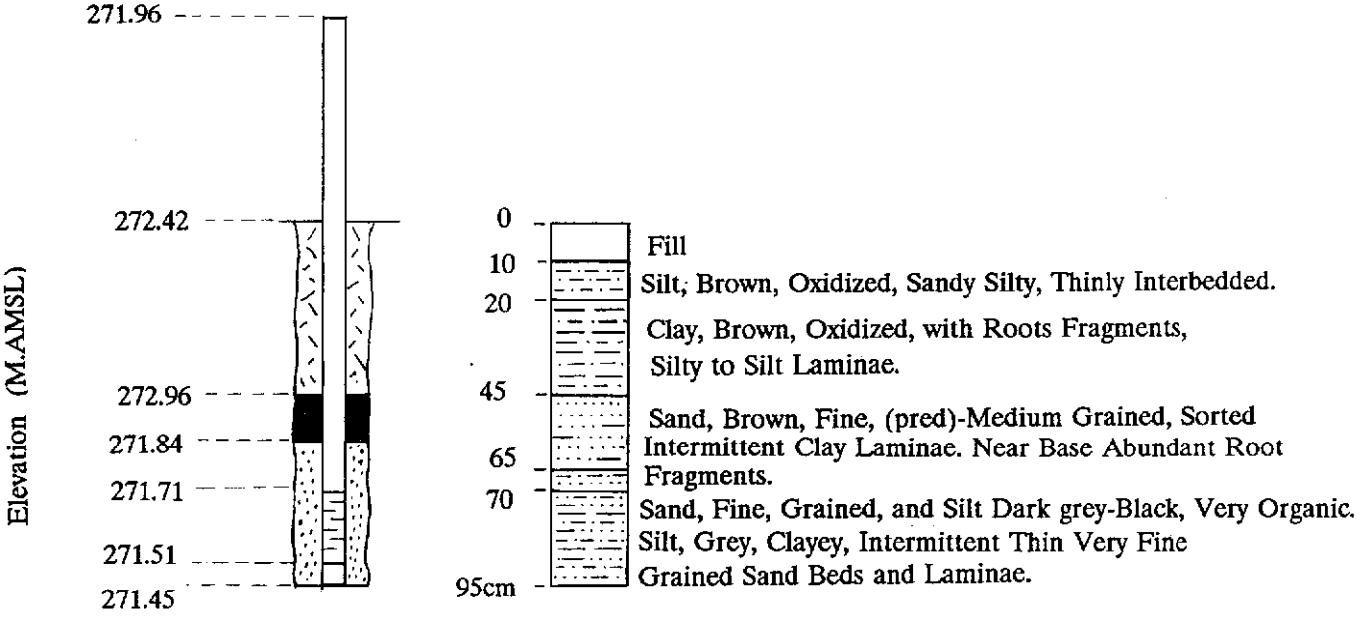


FIGURE 5: Stratigraphy and Completion Details of Piezometer: P-5

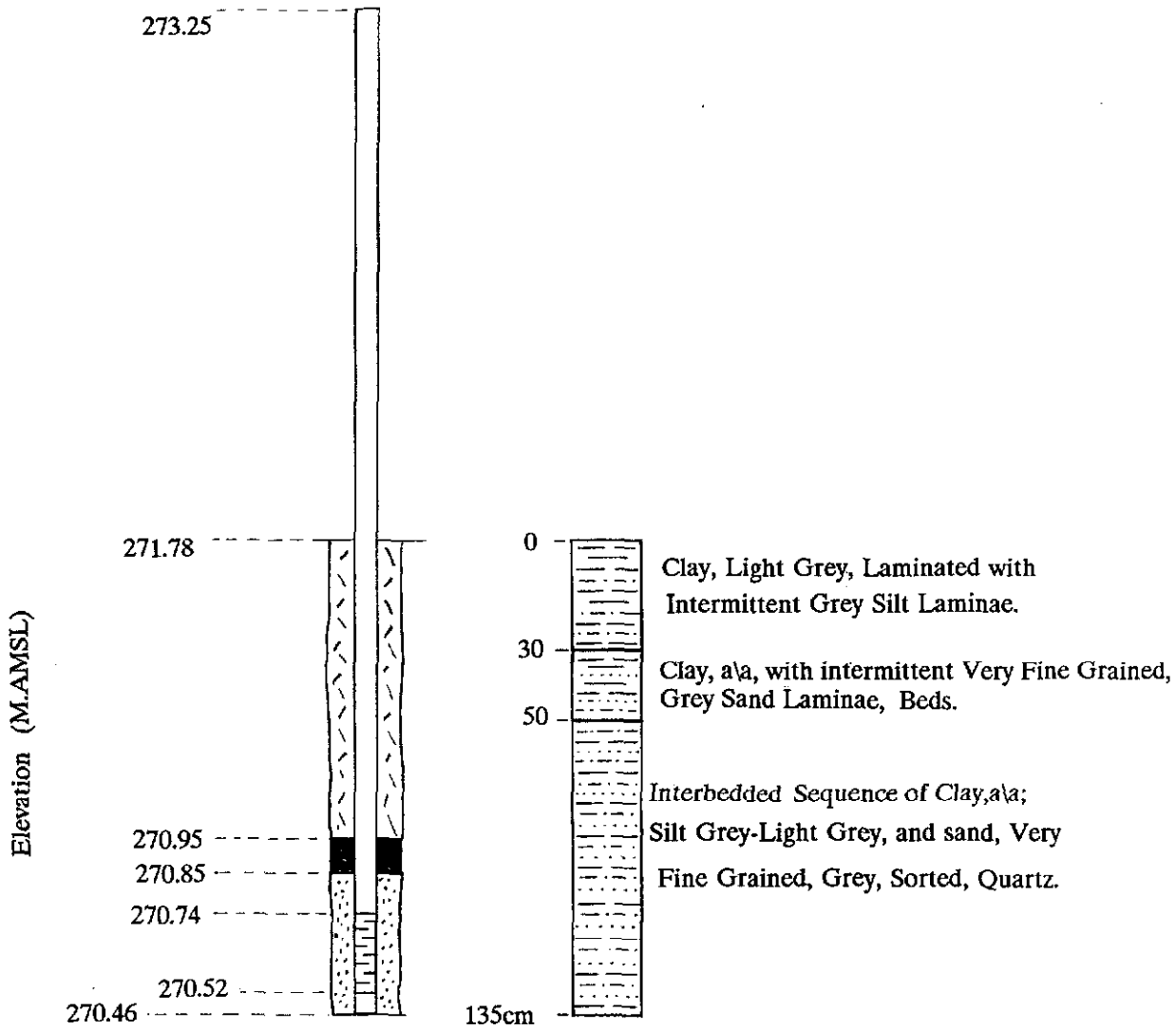


FIGURE 6: Stratigraphy and Completion Details of Piezometer: P-6

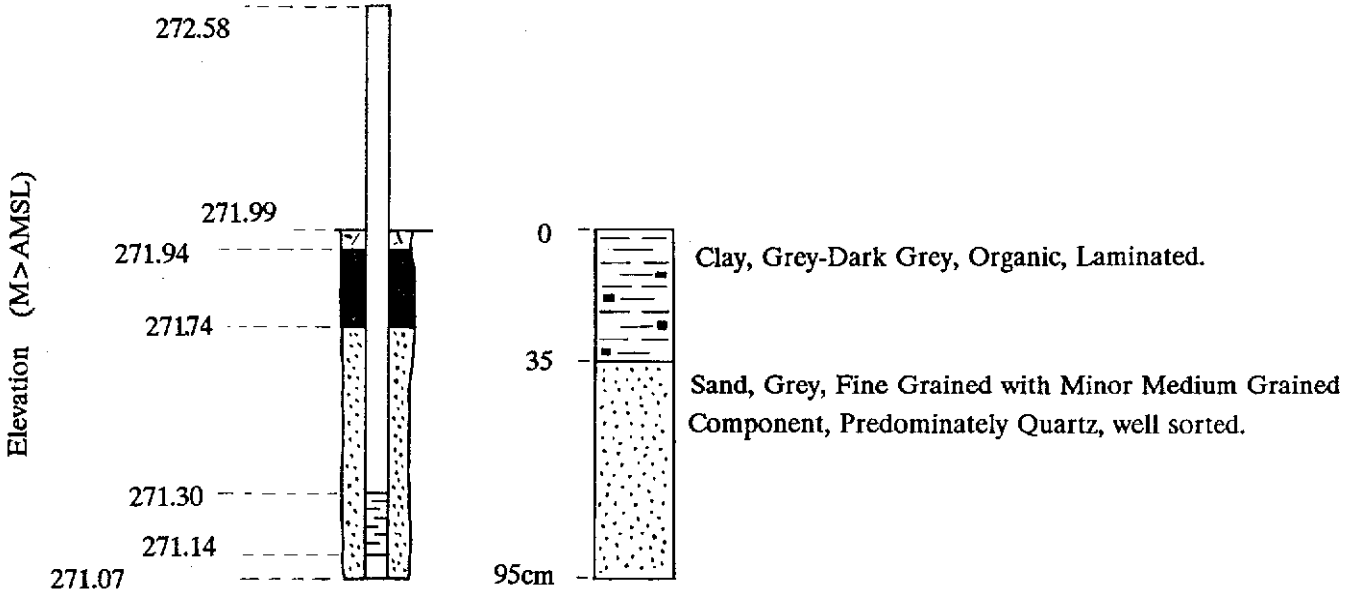


FIGURE 7: Stratigraphy and Completion Details of Piezometer: P-7

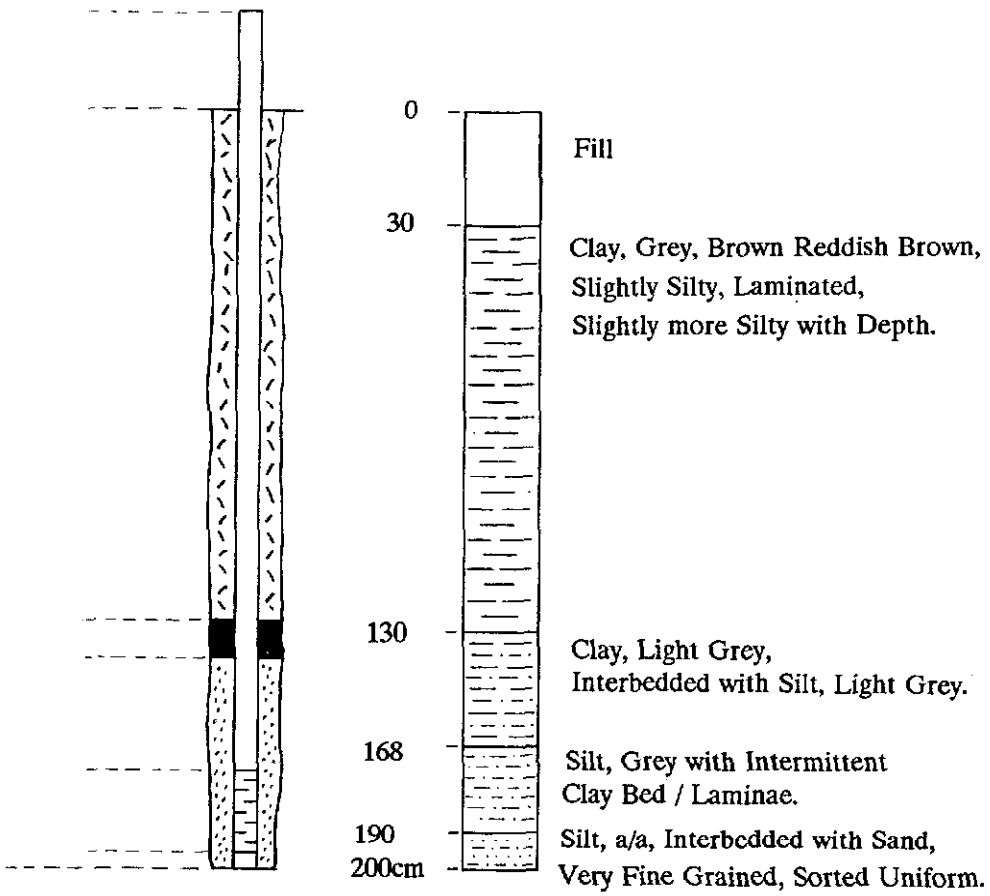


FIGURE 8: Stratigraphy and Completion Details of Piezometer: P-8

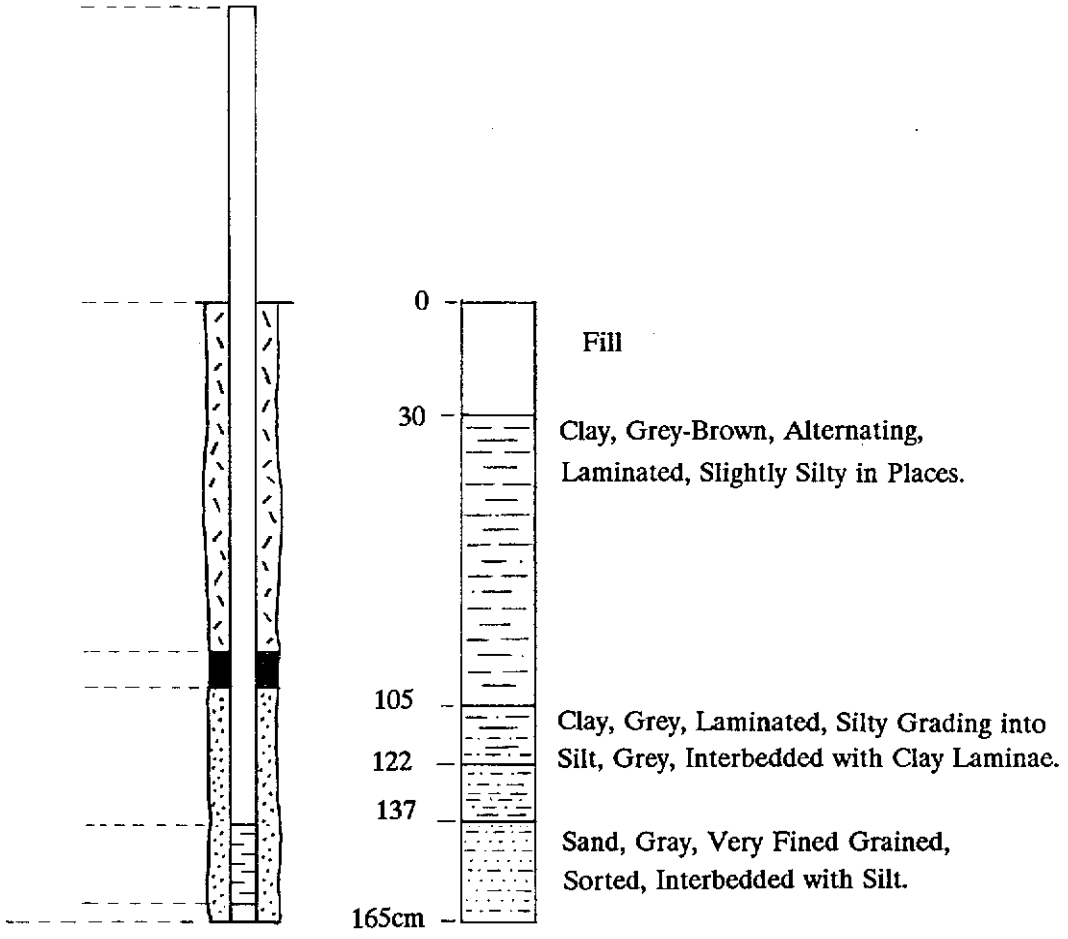


FIGURE 9: Stratigraphy and Completion Details of Piezometer: P-0

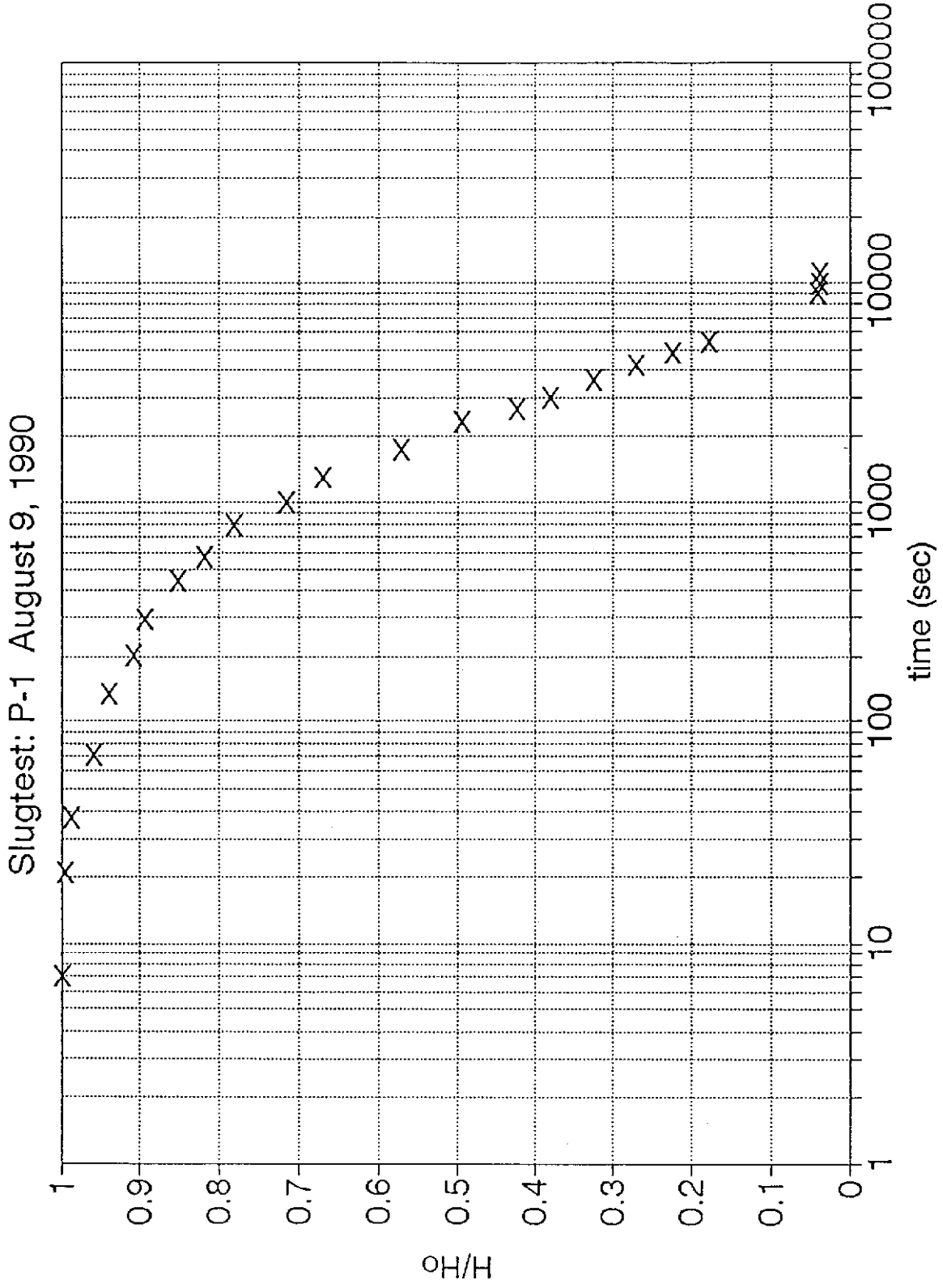


FIGURE 10: Slugtest Piezometer P-1

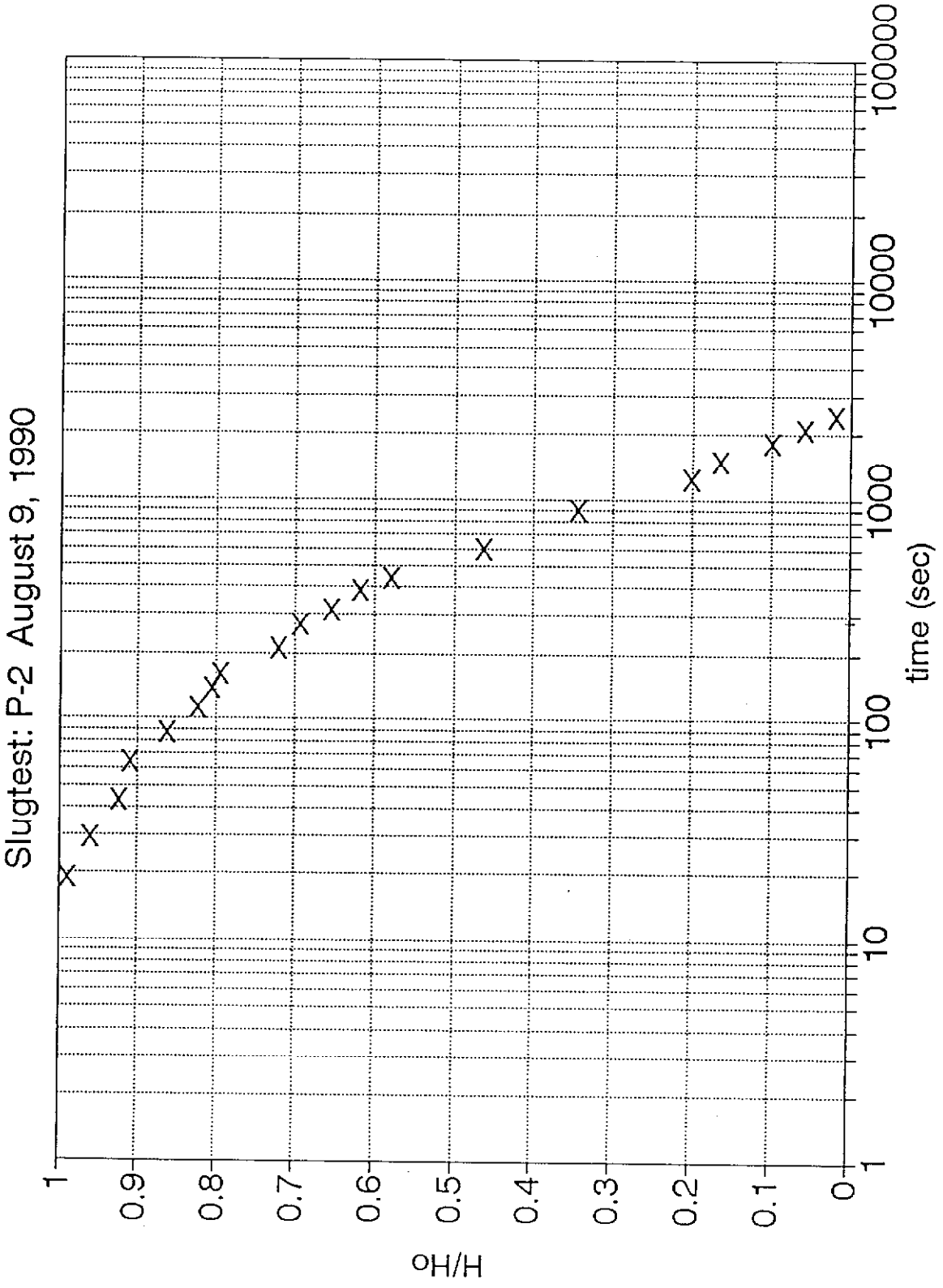


FIGURE 11: Slugtest Piezometer P-2

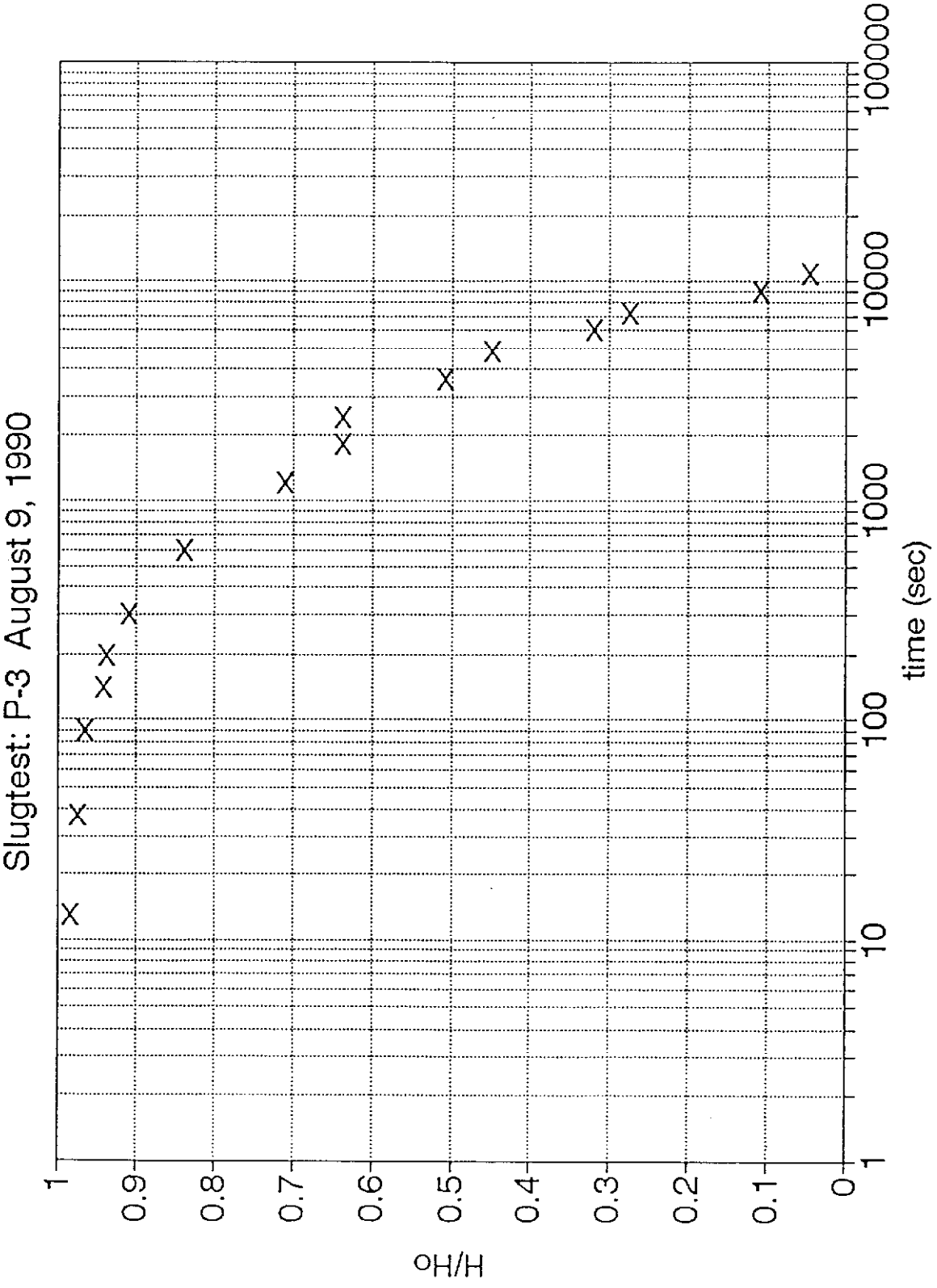


FIGURE 12: Slugtest Piezometer P-3

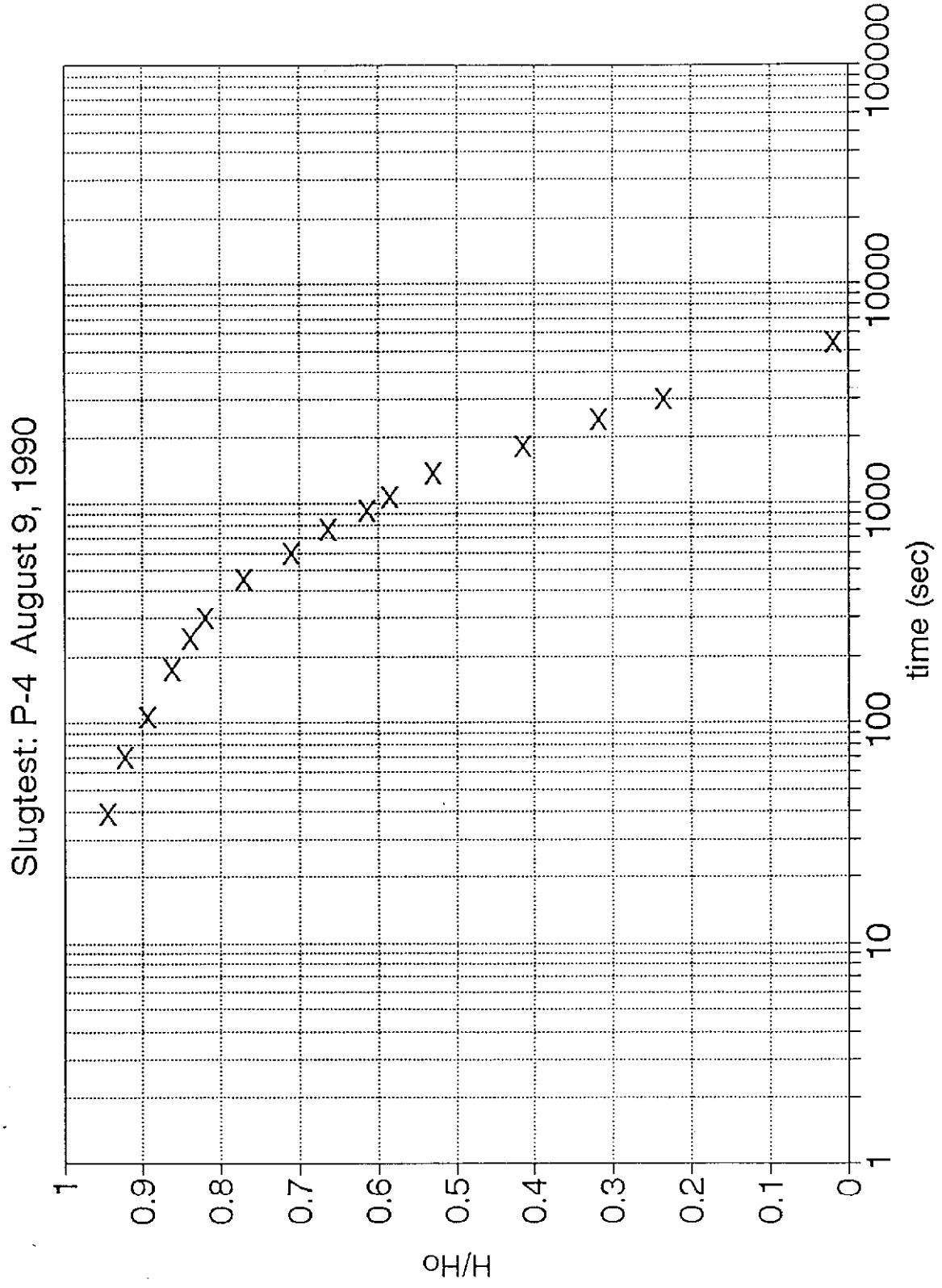


FIGURE 13: Slugtest Piezometer P-4

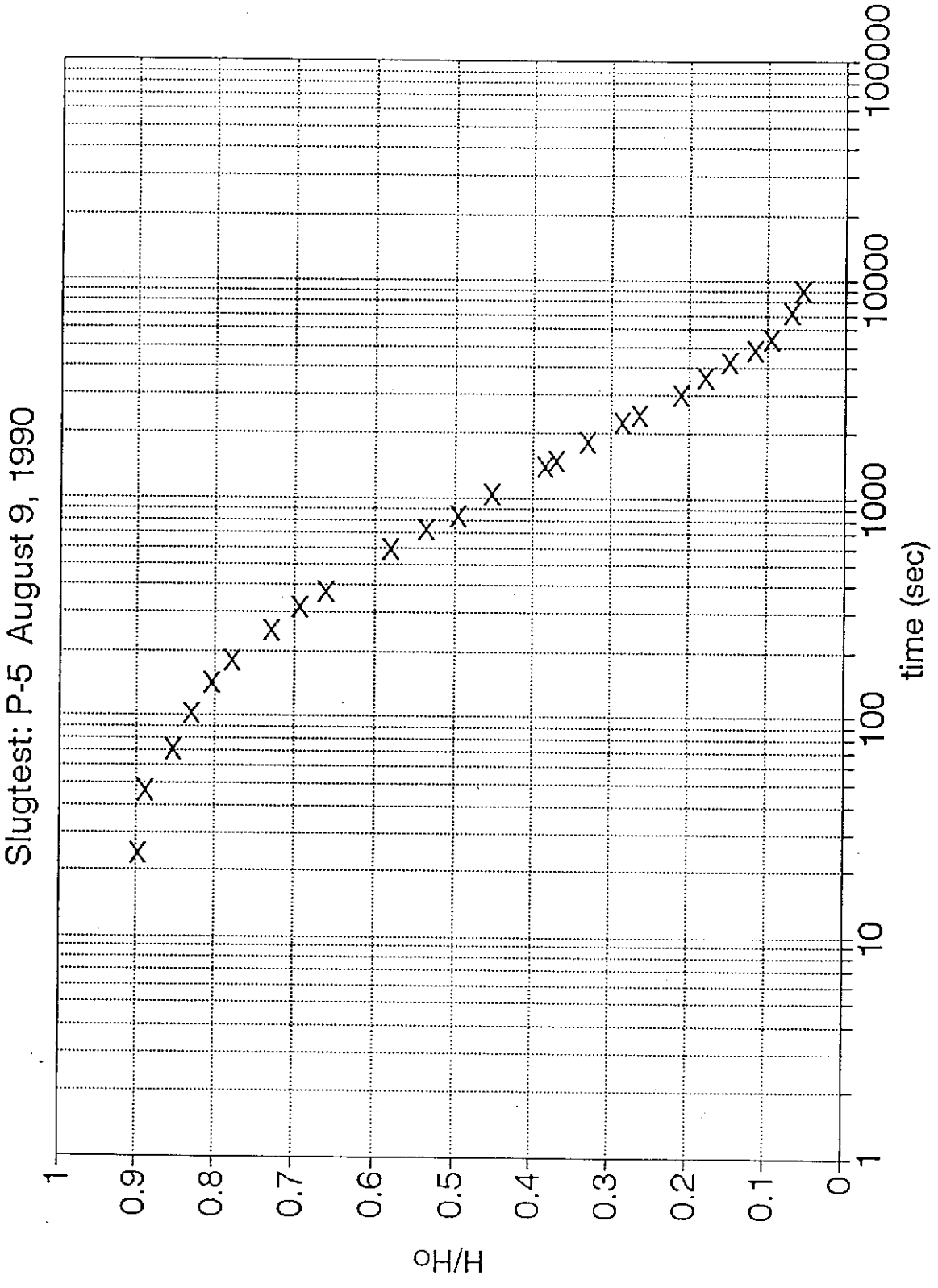


FIGURE 14: Slugtest Piezometer P-5

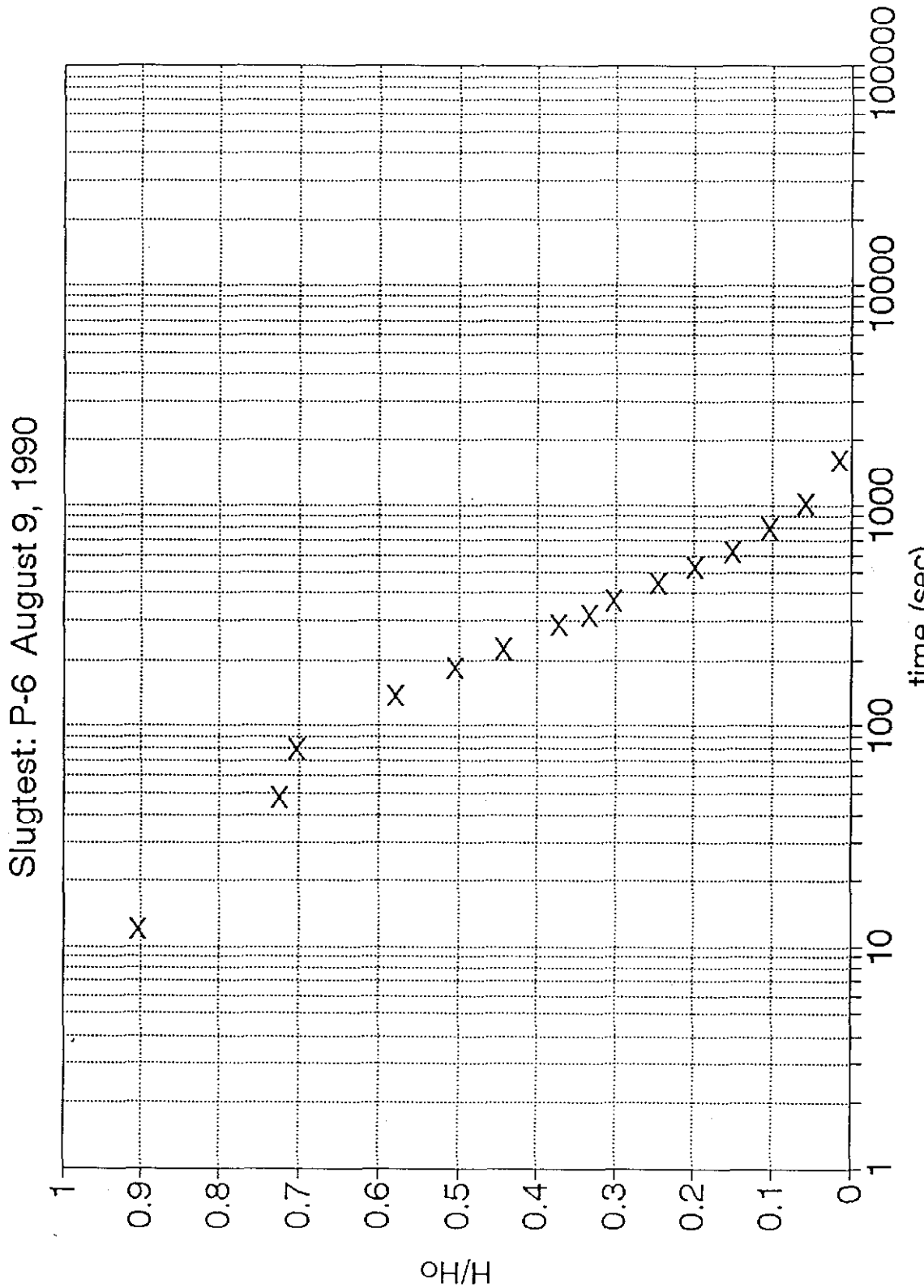


FIGURE 15: Slugtest Piezometer P-6

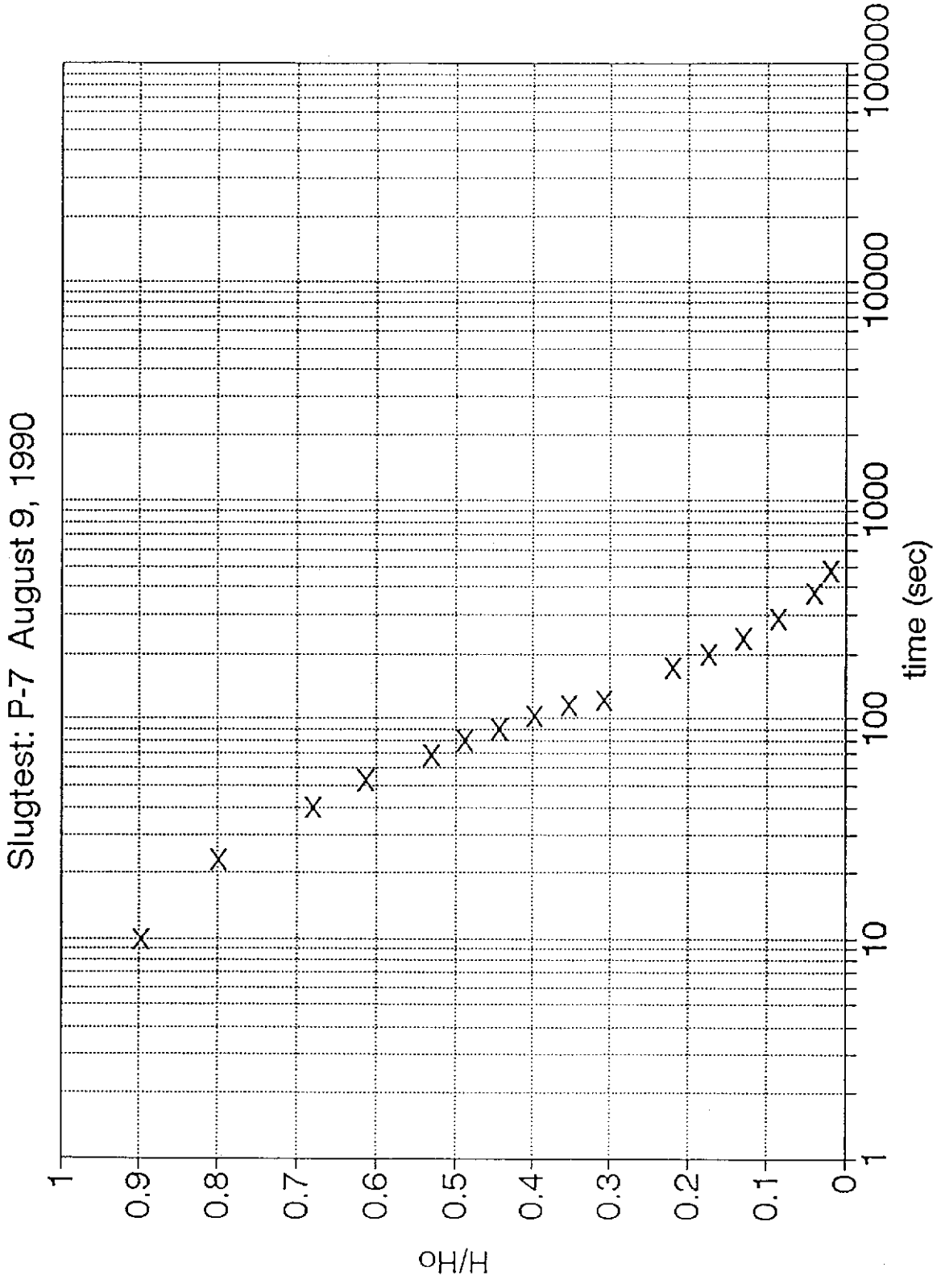


FIGURE 16: Slugtest Piezometer P-7

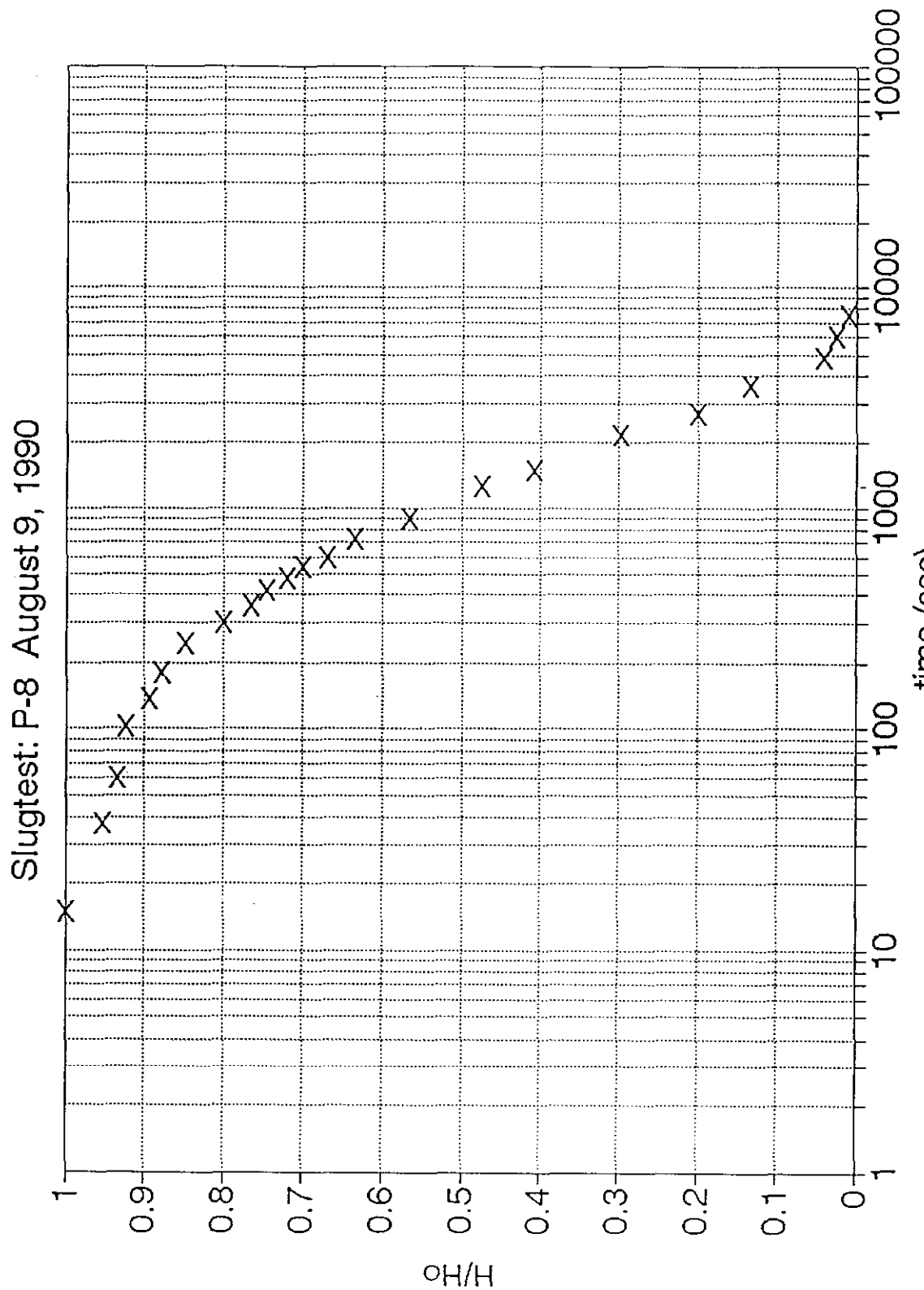


FIGURE 17: Slugtest Piezometer P-8

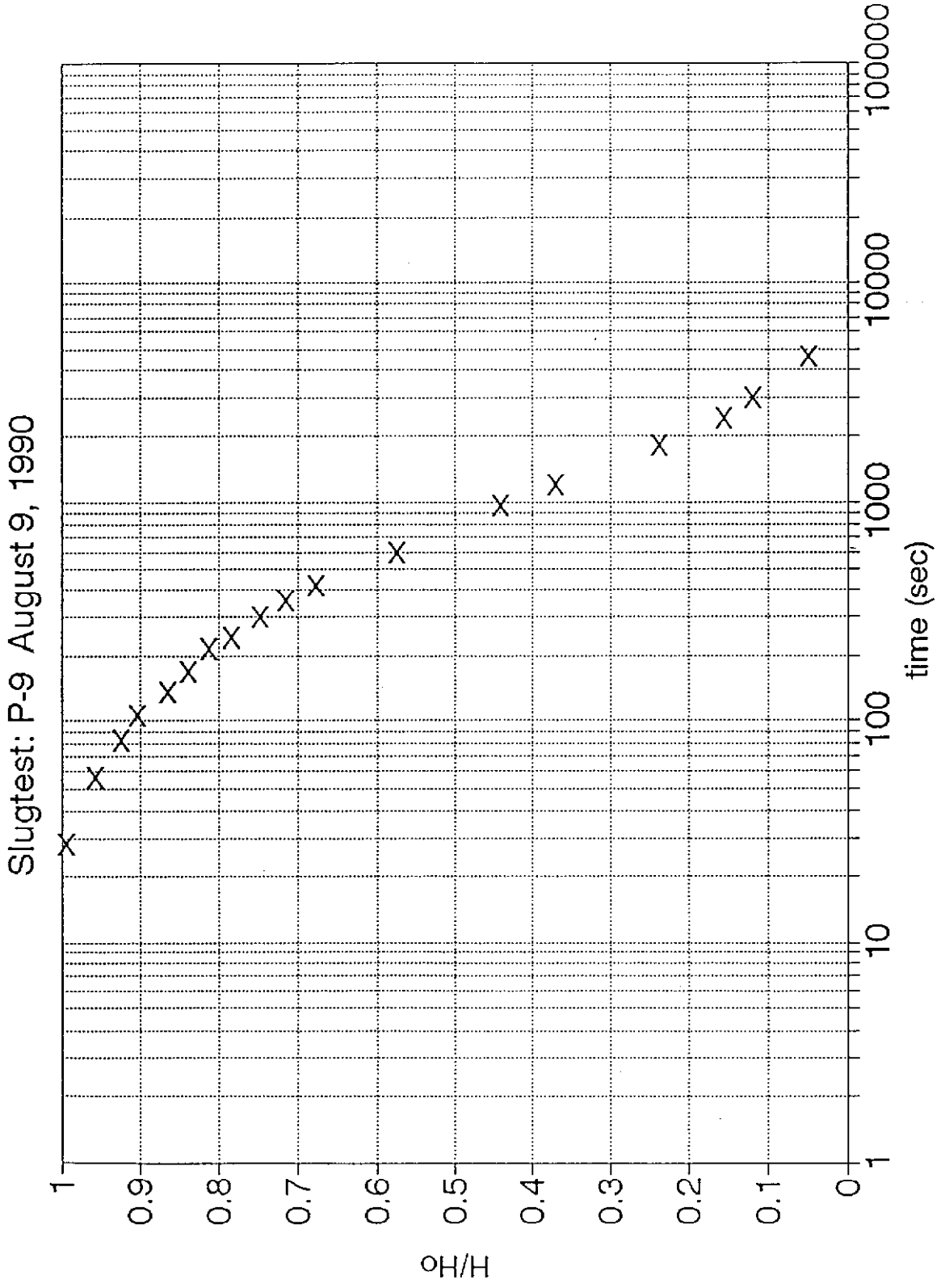
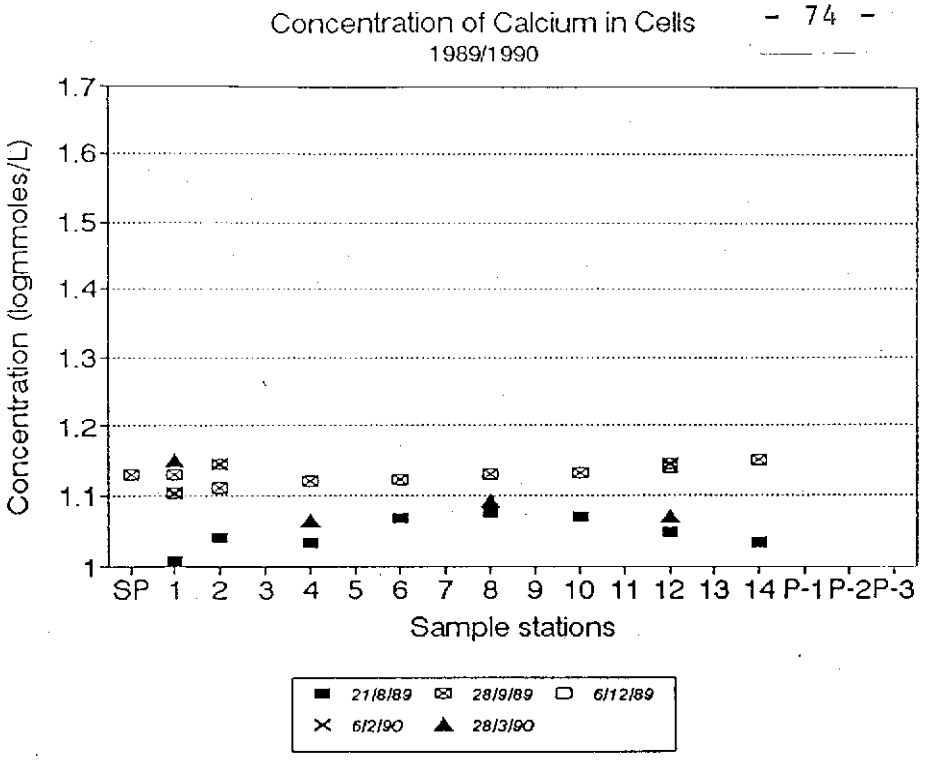


FIGURE 18: Slugtest Piezometer P-9



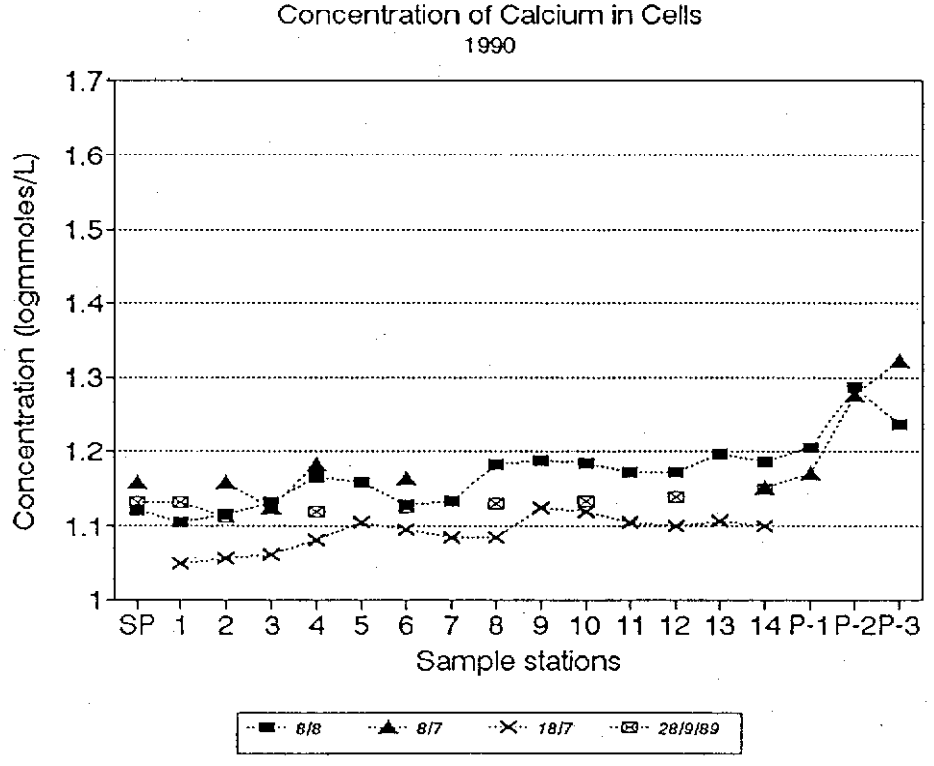
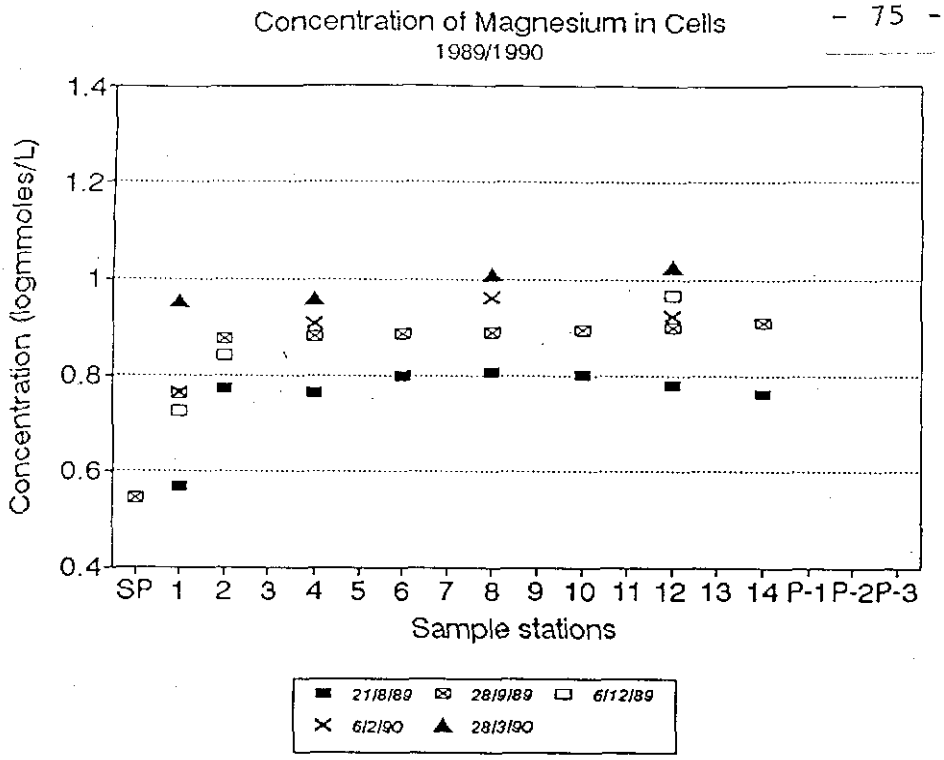


FIGURE 19: Concentration of Calcium in Cells: 1989/1990 and 1990



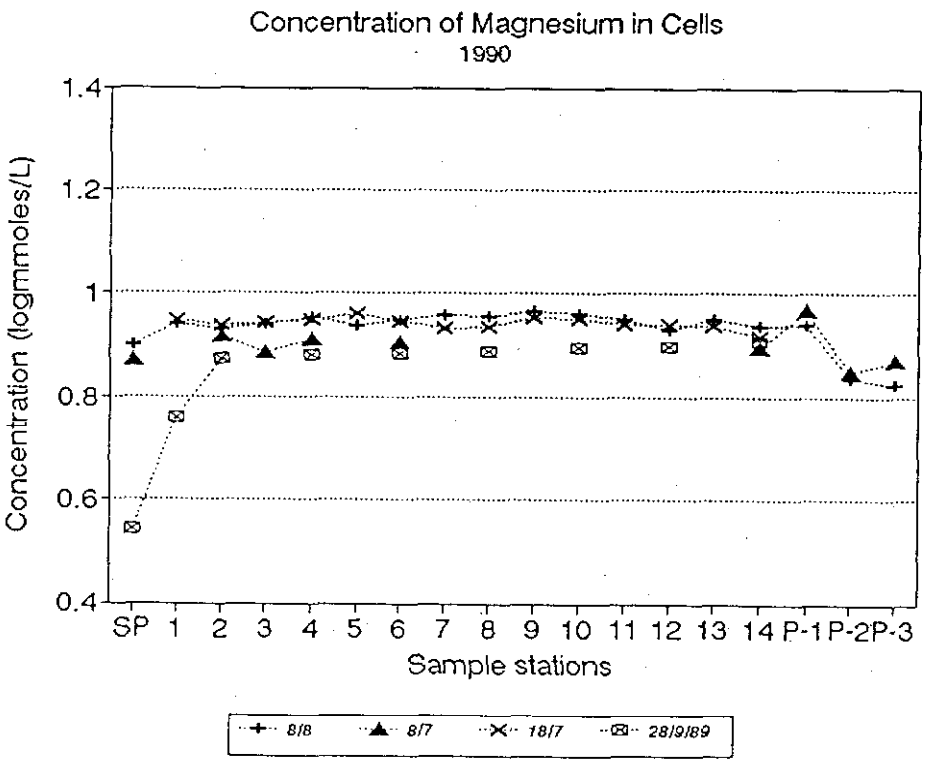
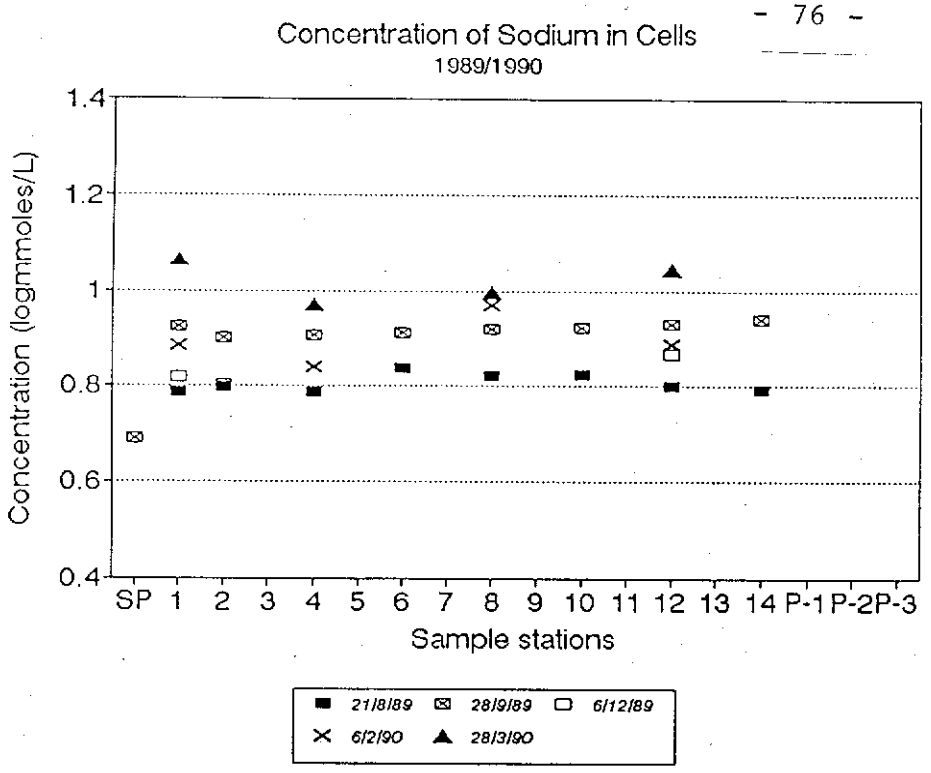


FIGURE 20: Concentration of Magnesium in Cells: 1989/1990 and 1990



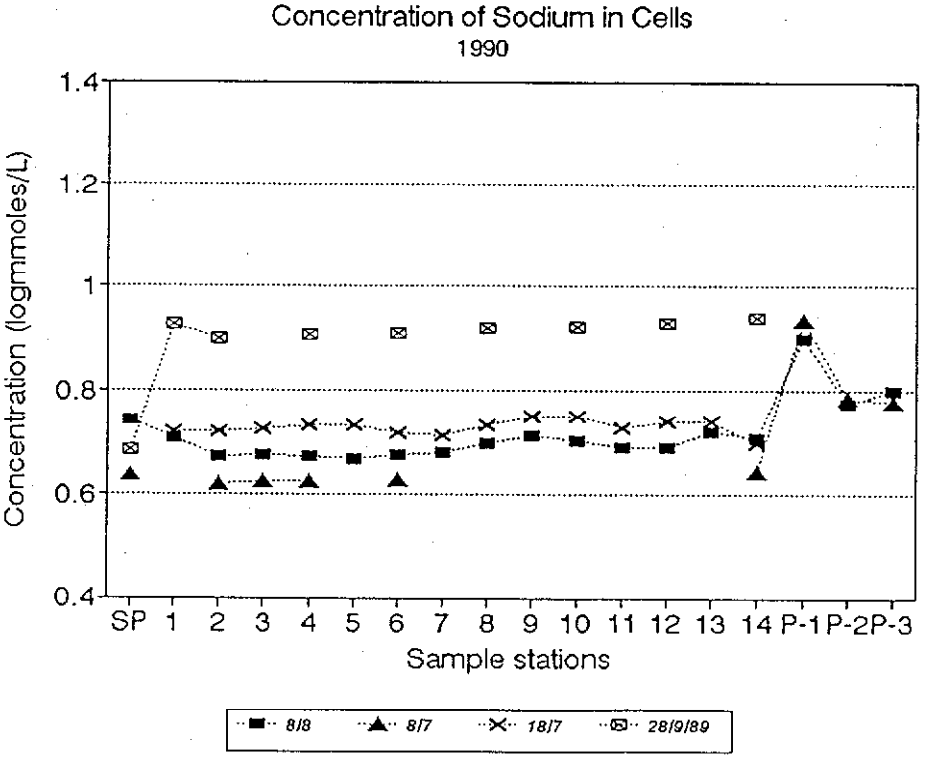
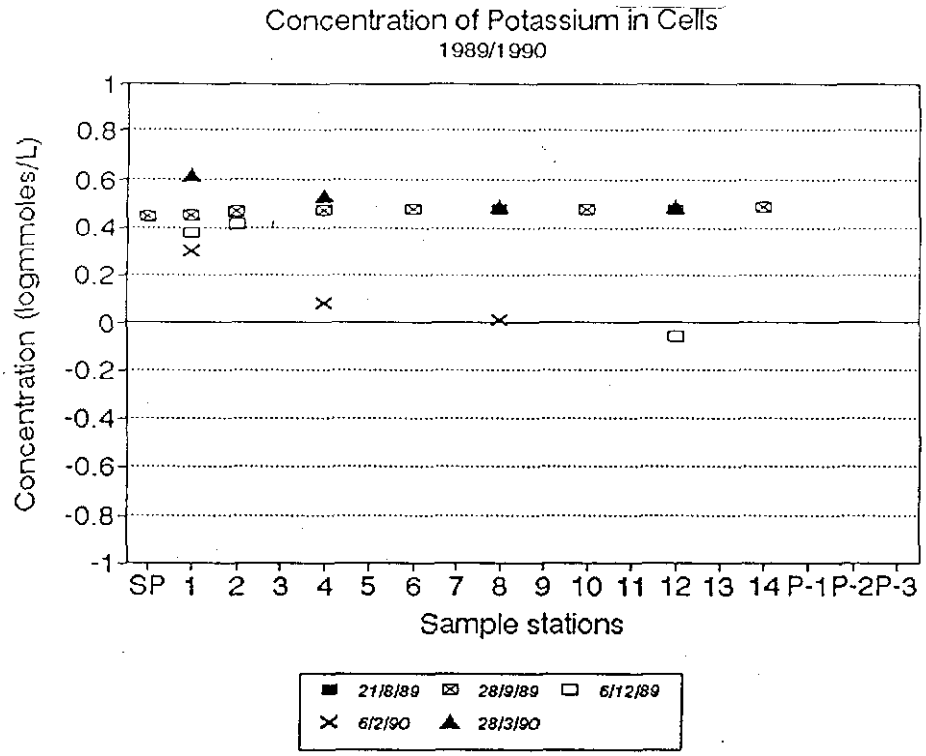


FIGURE 21: Concentration of Sodium in Cells: 1989/1990 and 1990



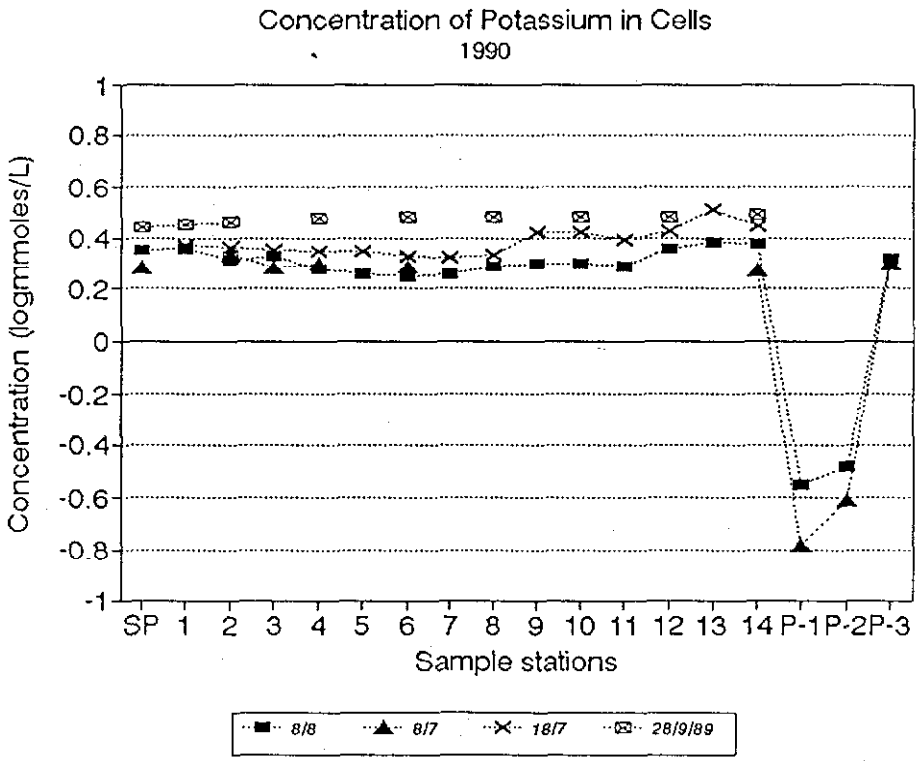
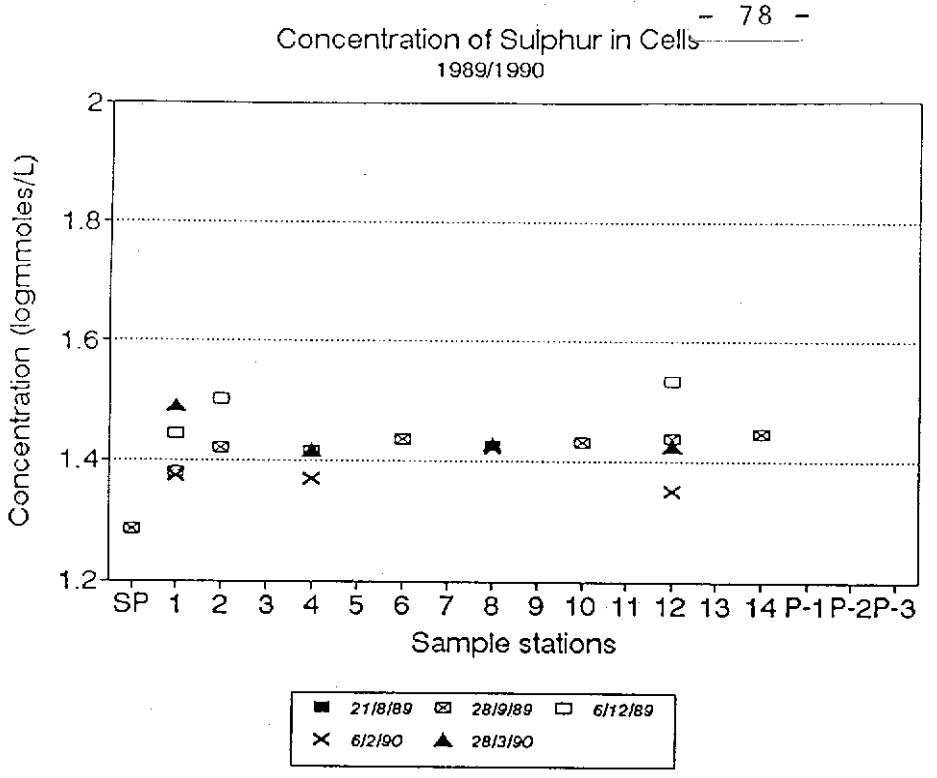


FIGURE 22: Concentration of Potassium in Cells: 1989/1990 and 1990



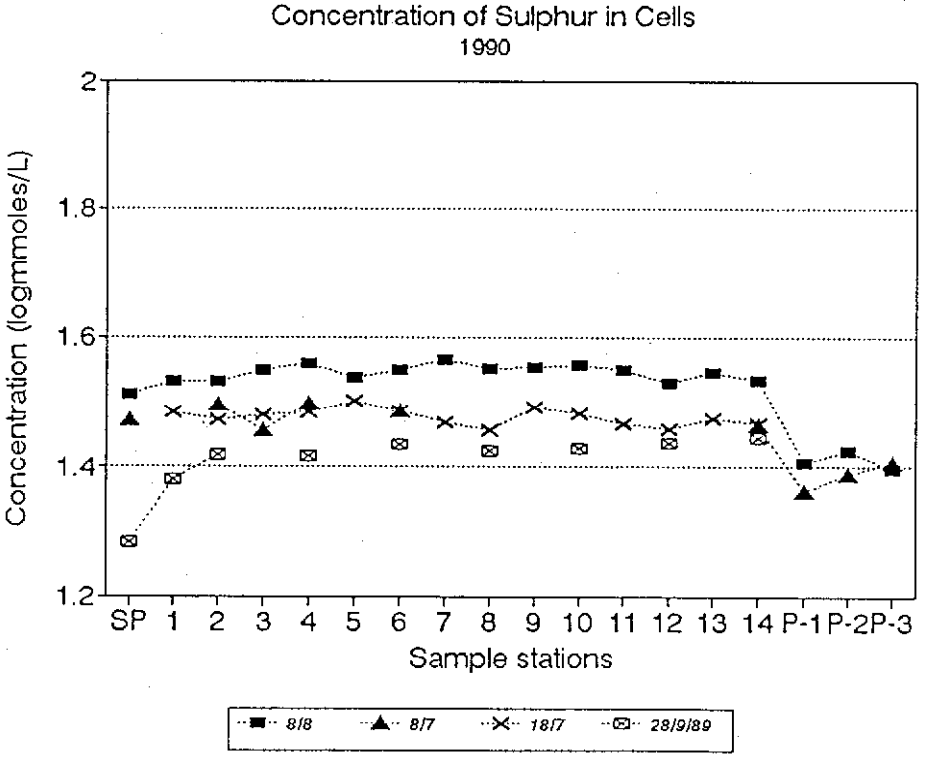
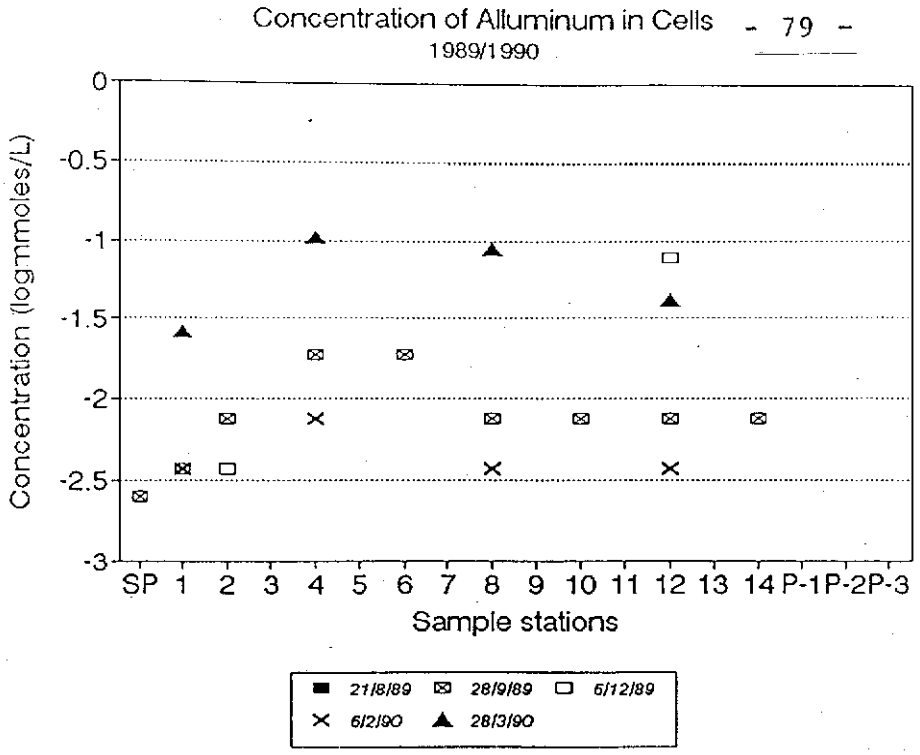


FIGURE 23: Concentration of Sulphur in Cells: 1989/1990 and 1990



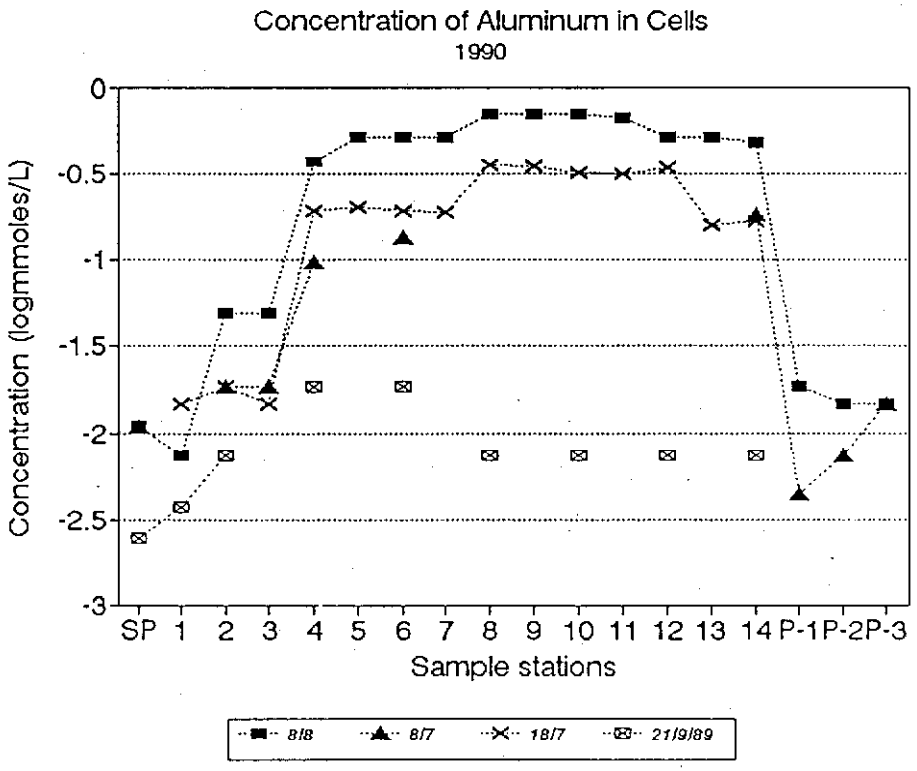
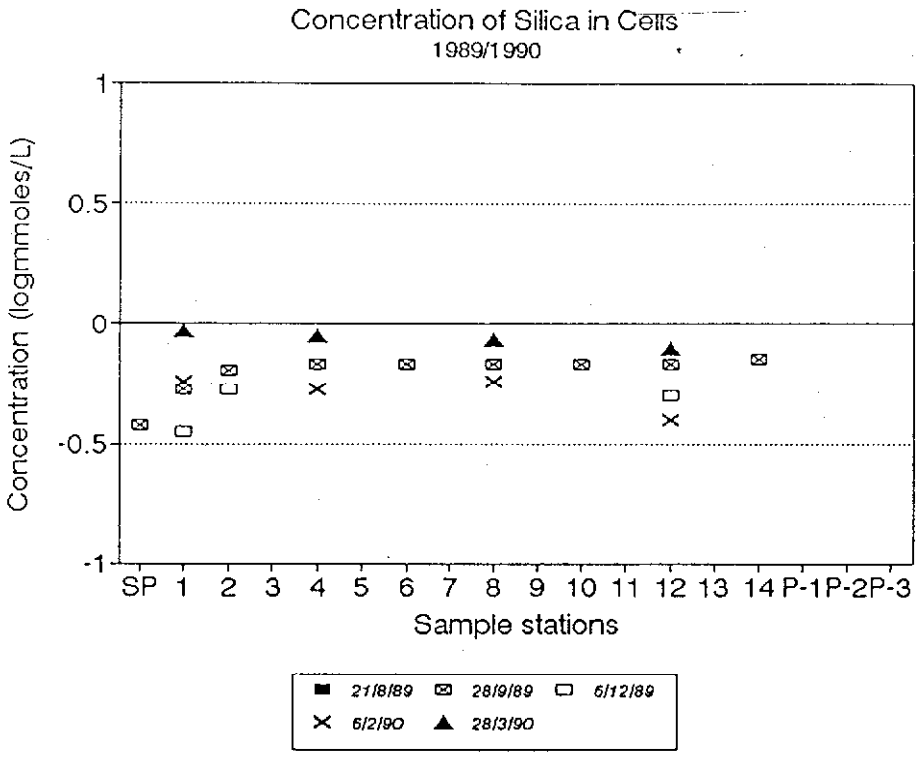


FIGURE 24: Concentration of Aluminum in Cells: 1989/1990 and 1990



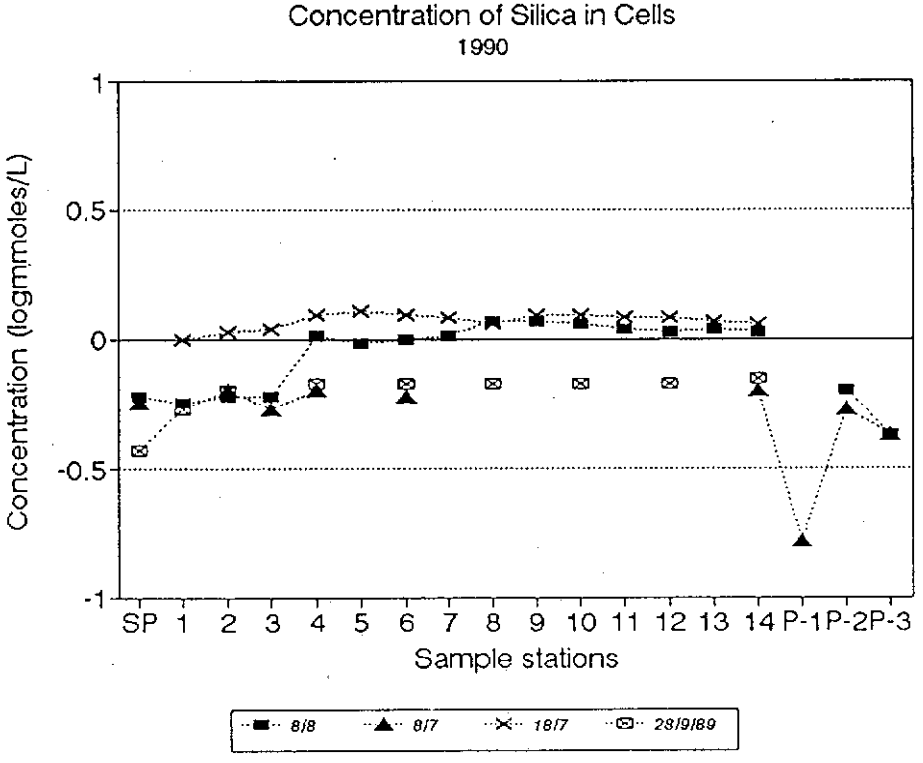
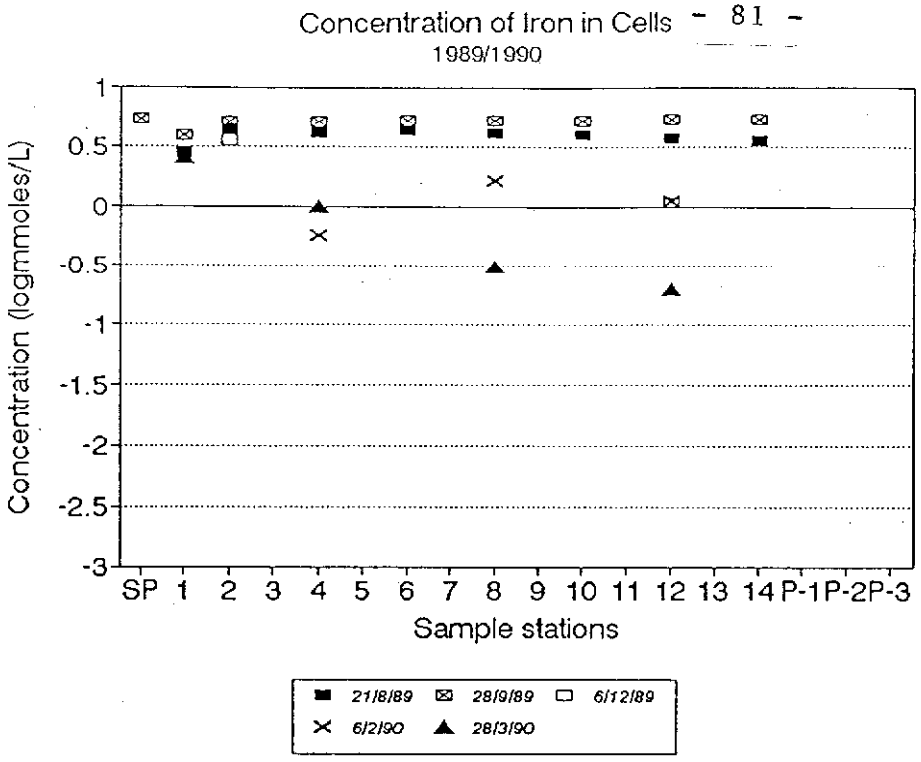


FIGURE 25: Concentration of Silica in Cells: 1989/1990 and 1990



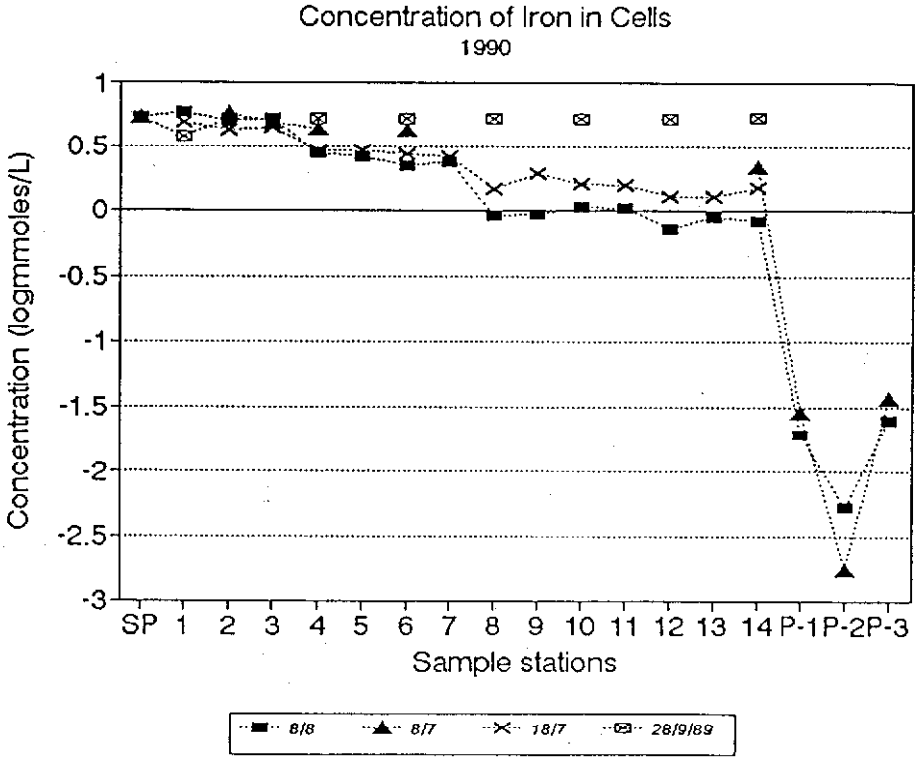
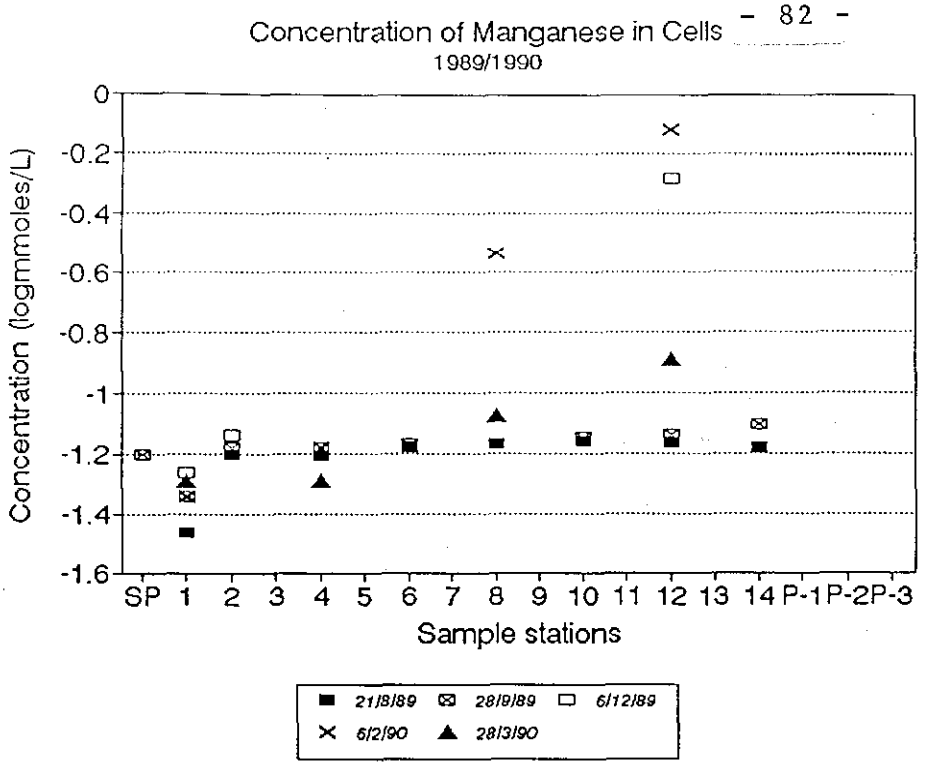


FIGURE 26: Concentration of Iron in Cells: 1989/1990 and 1990



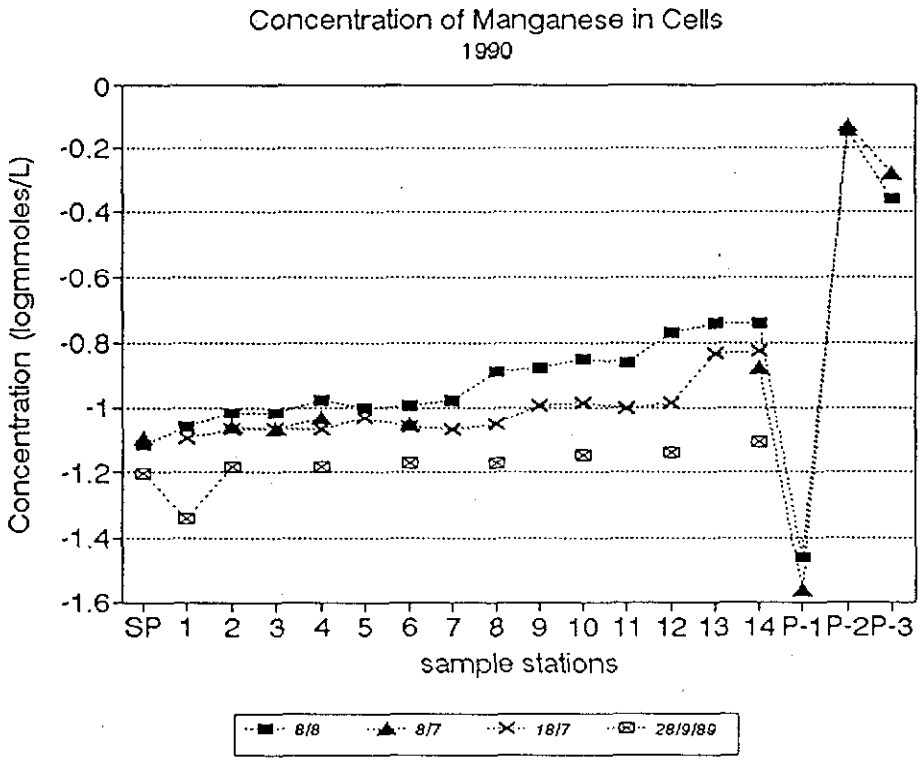
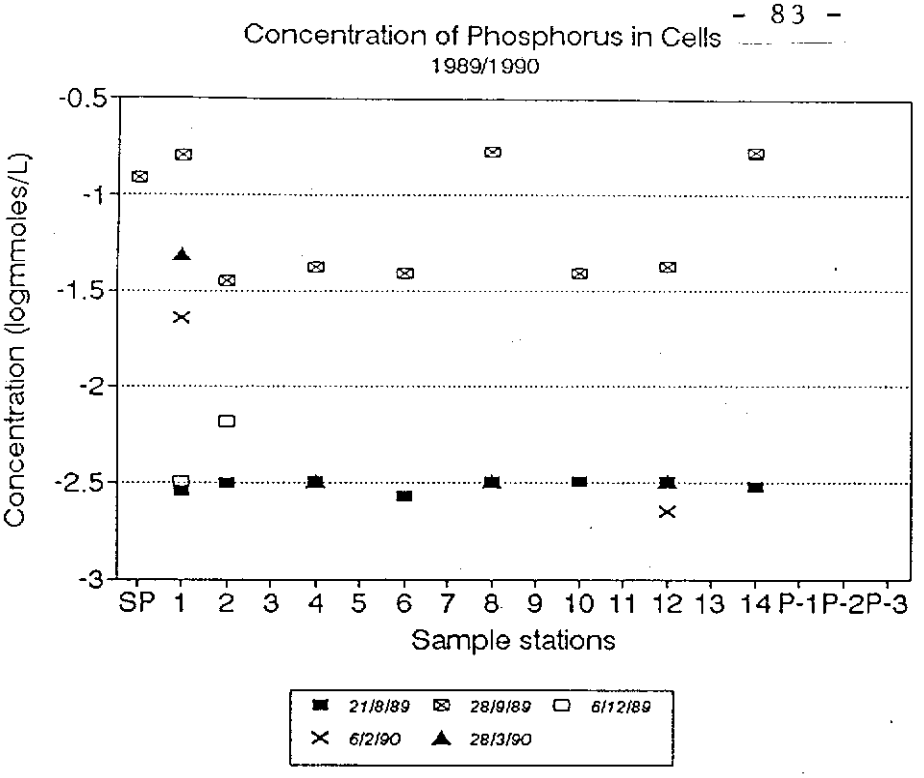


FIGURE 27: Concentration of Manganese in Cells: 1989/1990 and 1990



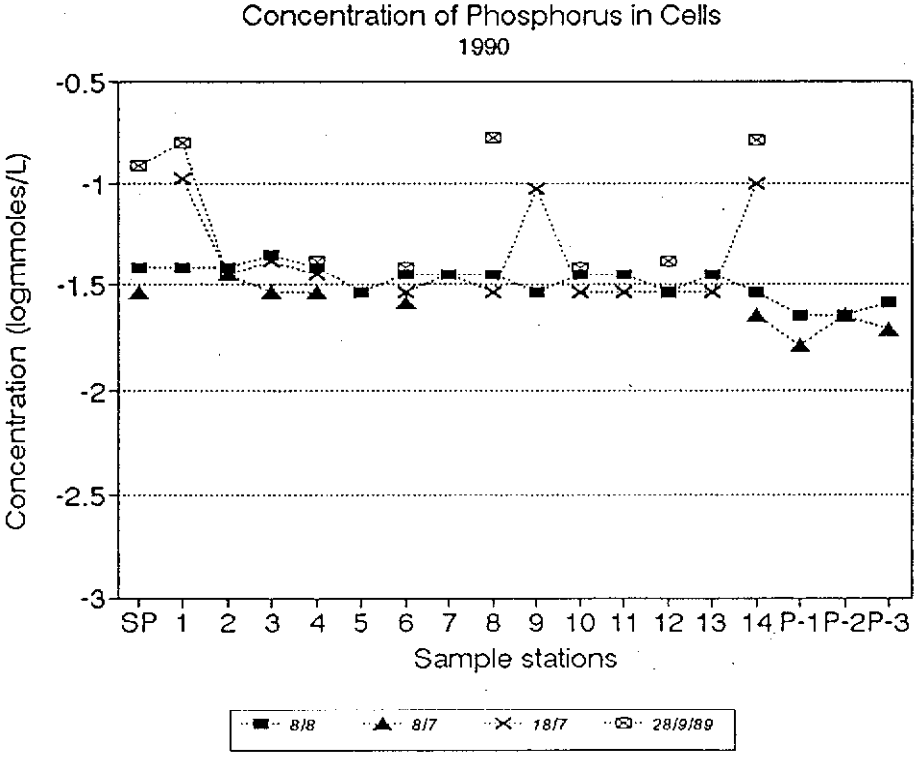
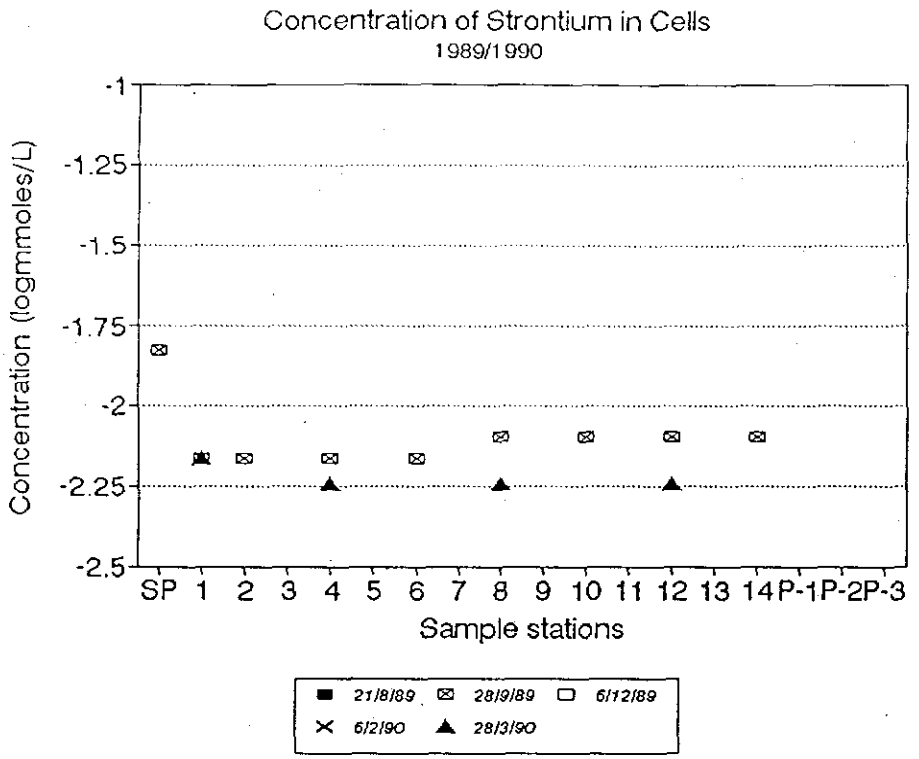


FIGURE 28: Concentration of Phosphorus in Cells: 1989/1990 and 1990



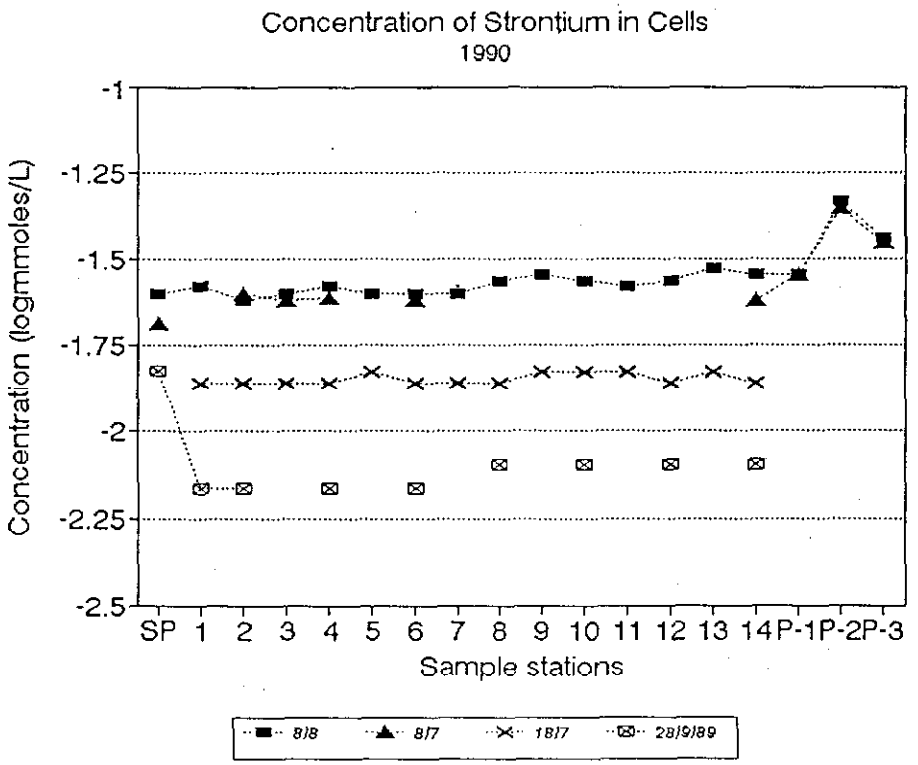
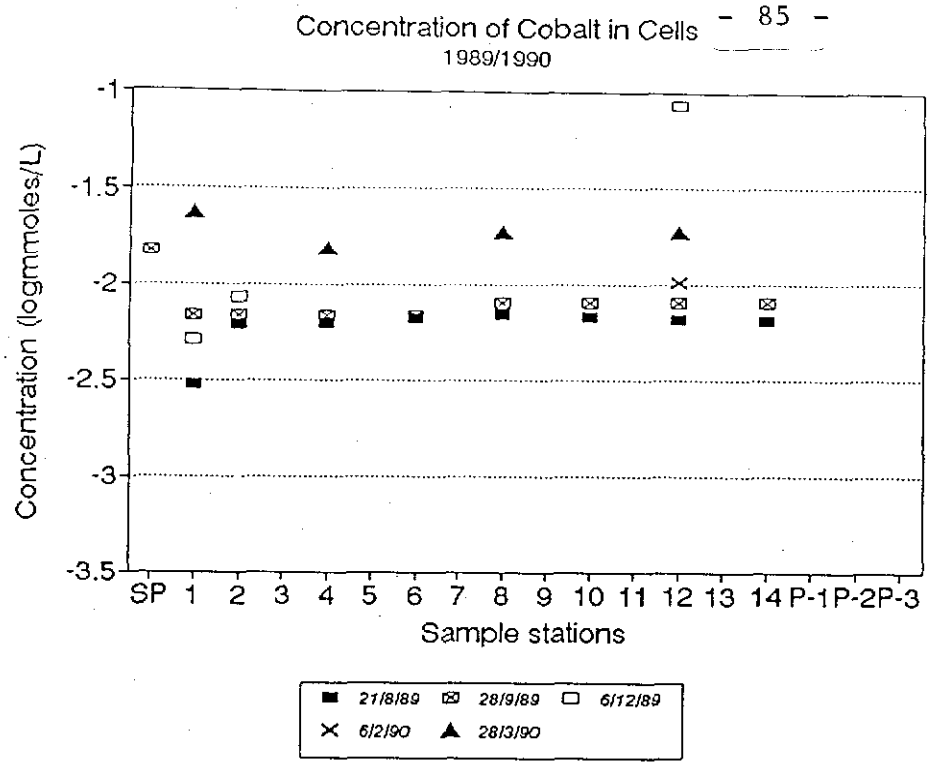


FIGURE 29: Concentration of Strontium in Cells: 1989/1990 and 1990



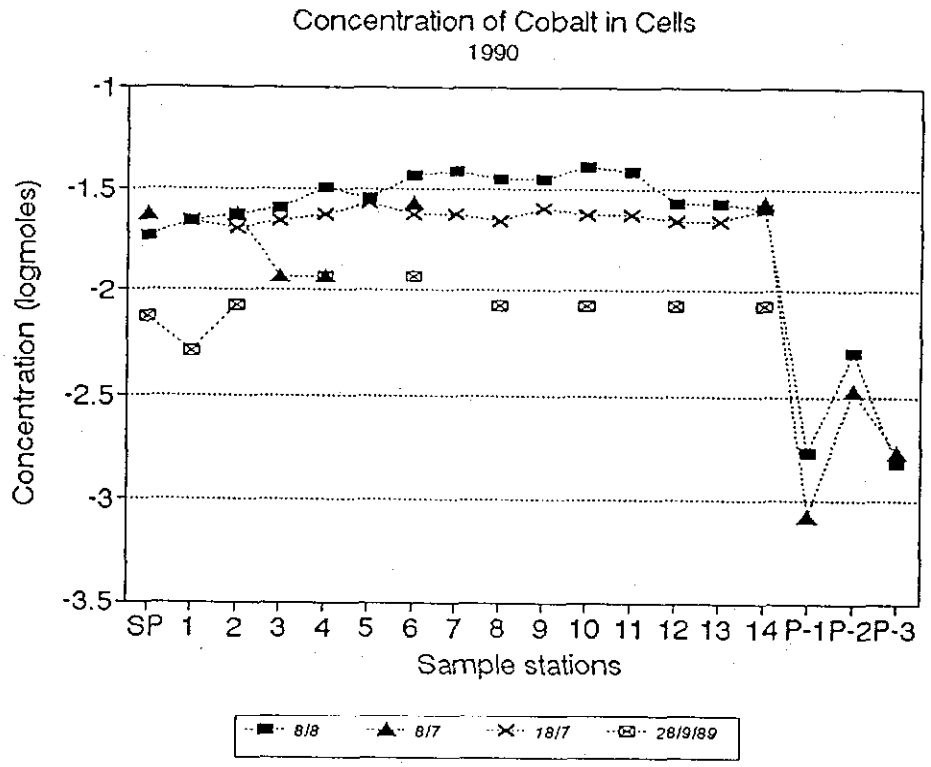
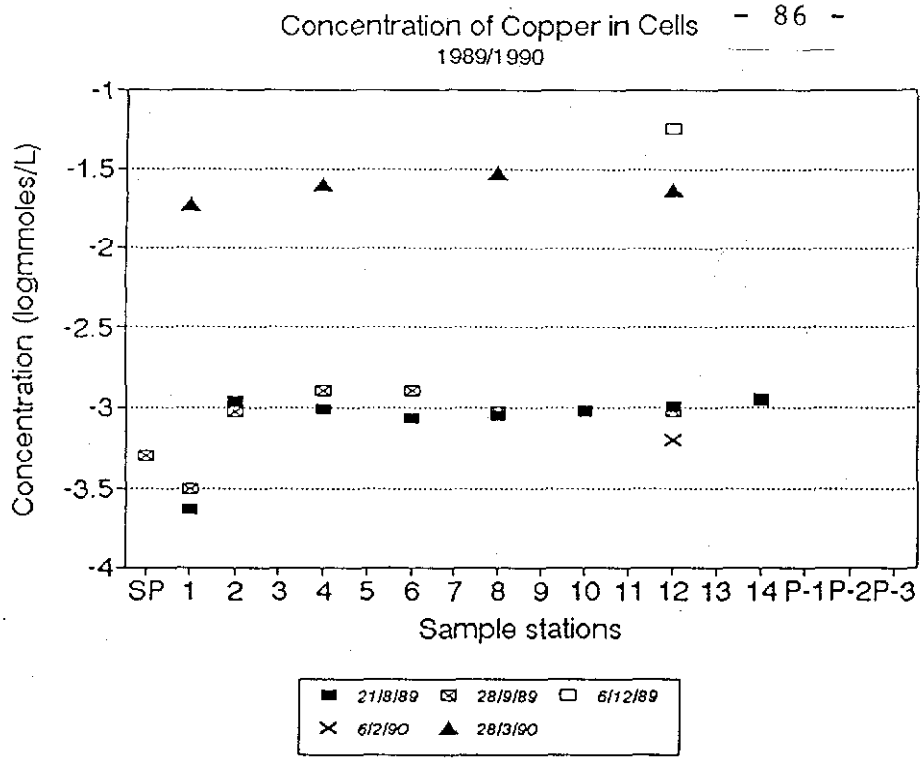


FIGURE 30: Concentration of Cobalt in Cells: 1989/1990 and 1990



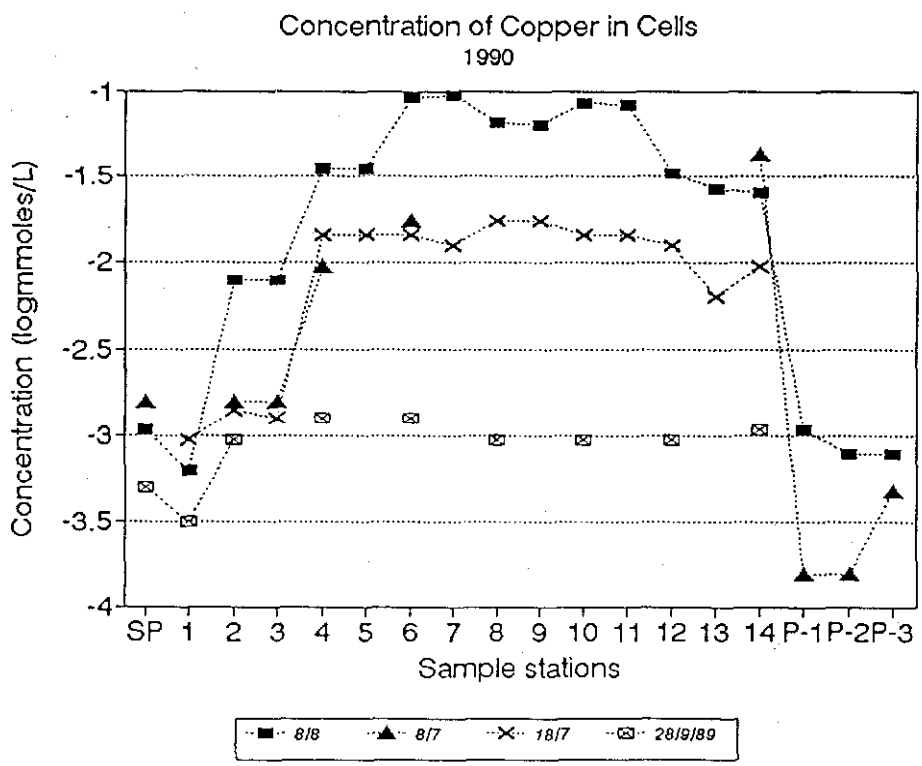
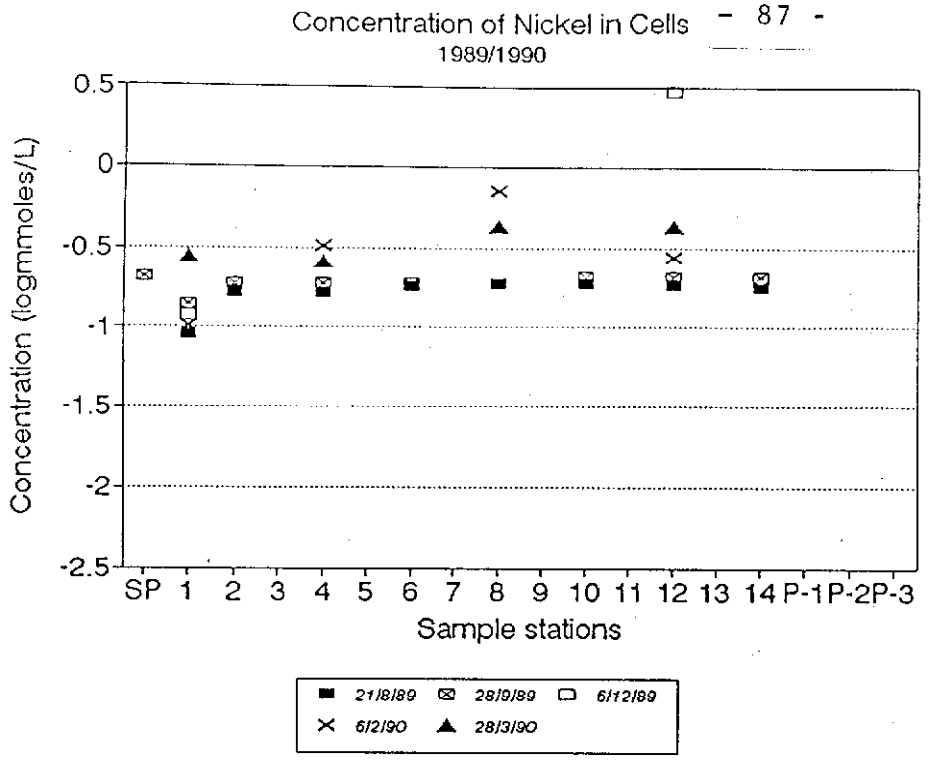


FIGURE 31: Concentration of Copper in Cells: 1989/1990 and 1990



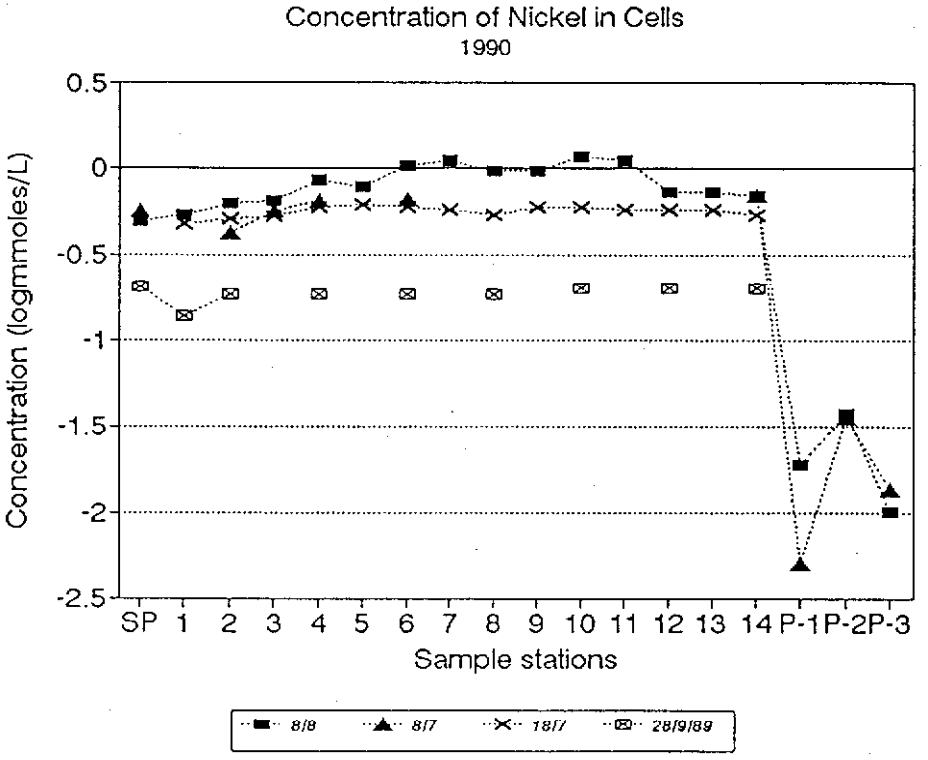
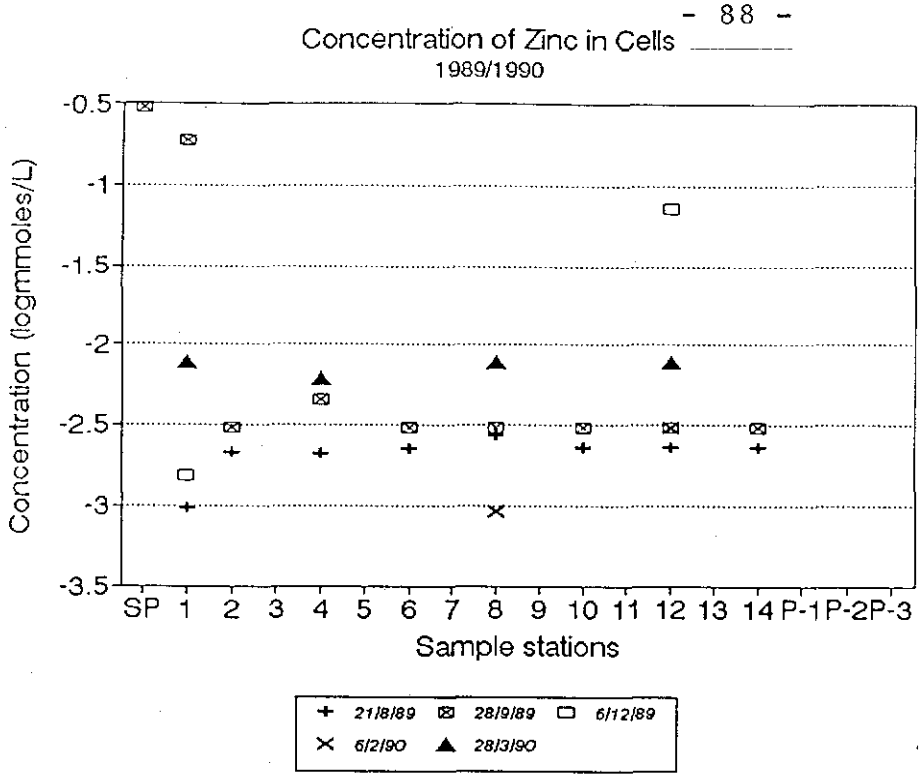


FIGURE 32: Concentration of Nickel in Cells: 1989/1990 and 1990



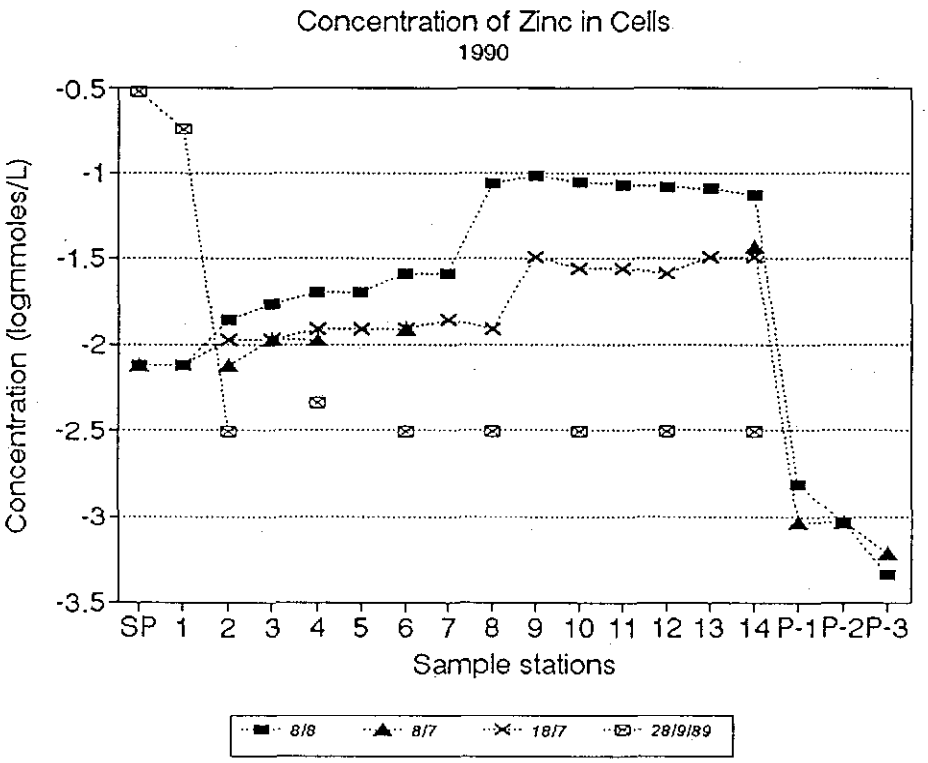


FIGURE 33 Concentration of Zinc in Cells: 1989/1990 and 1990

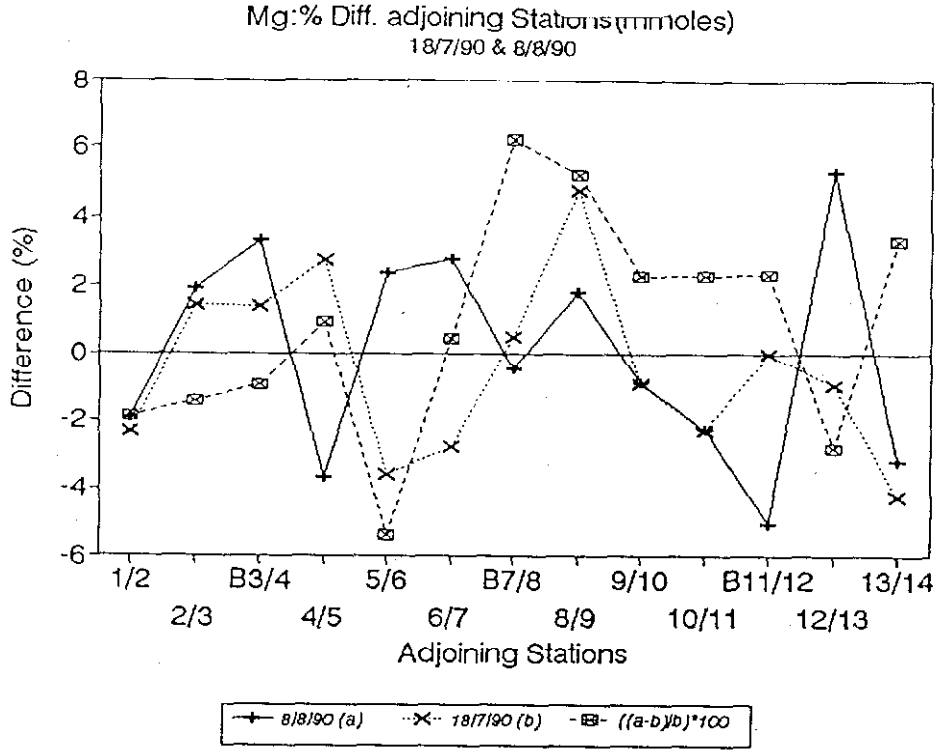


FIGURE 34a: Magnesium: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

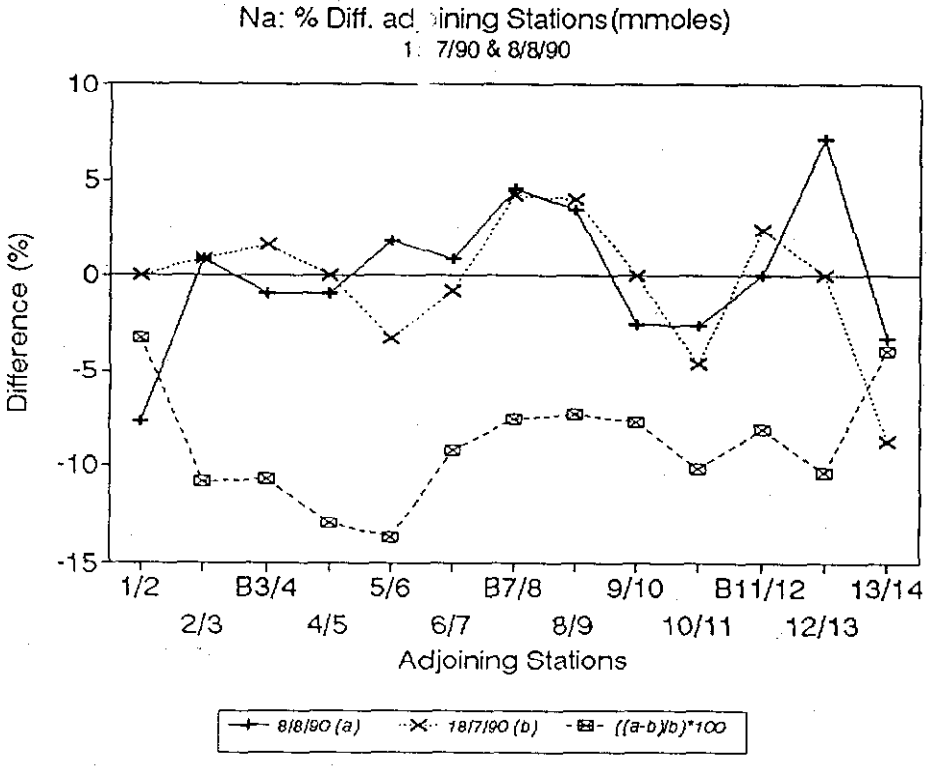


FIGURE 34b: Sodium: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

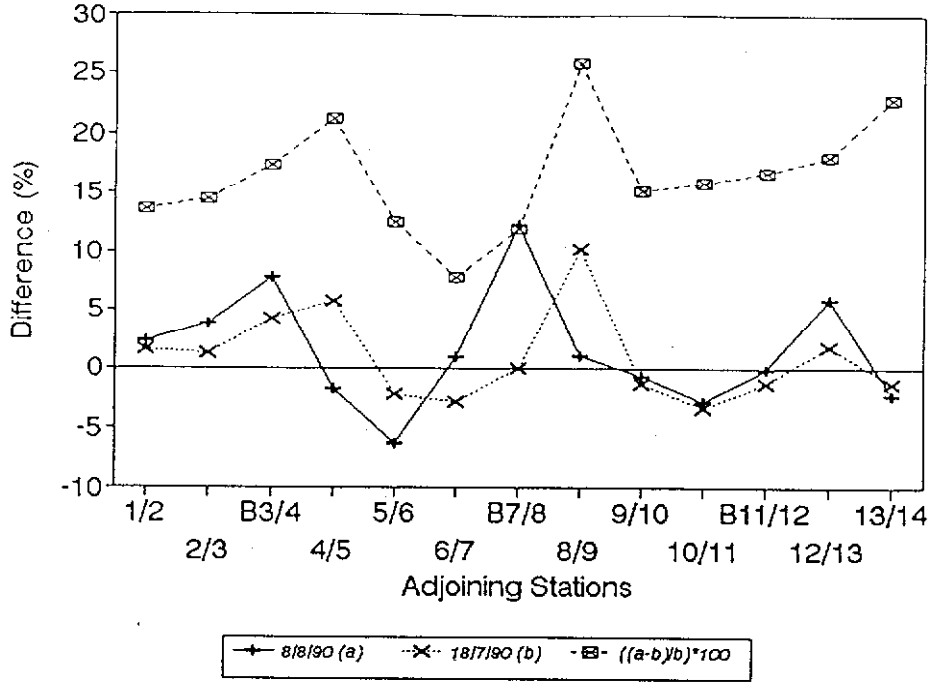


FIGURE 35a: Calcium: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

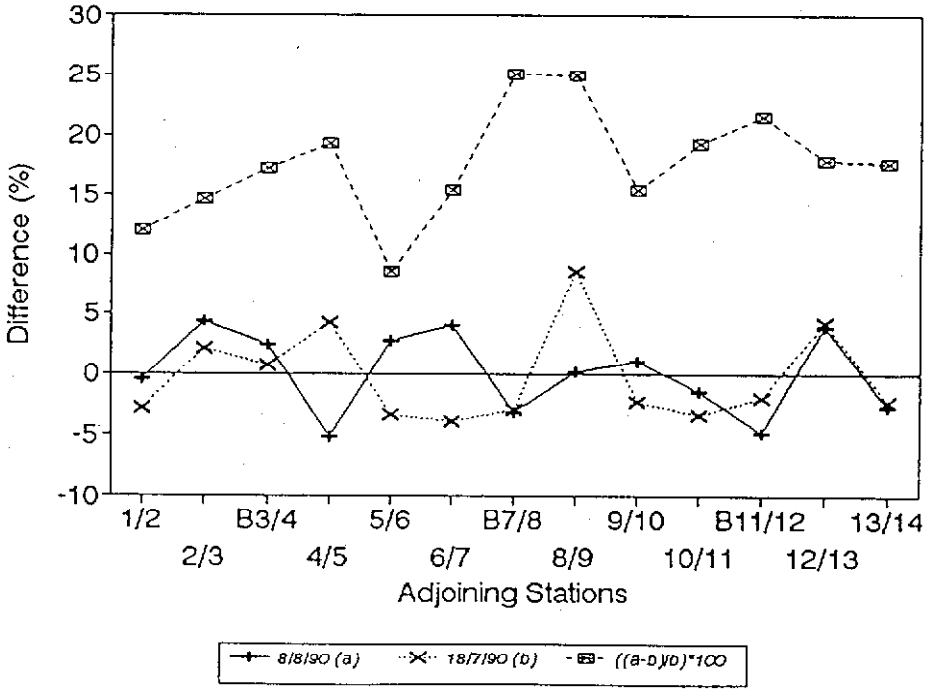


FIGURE 35b: Sulphur: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

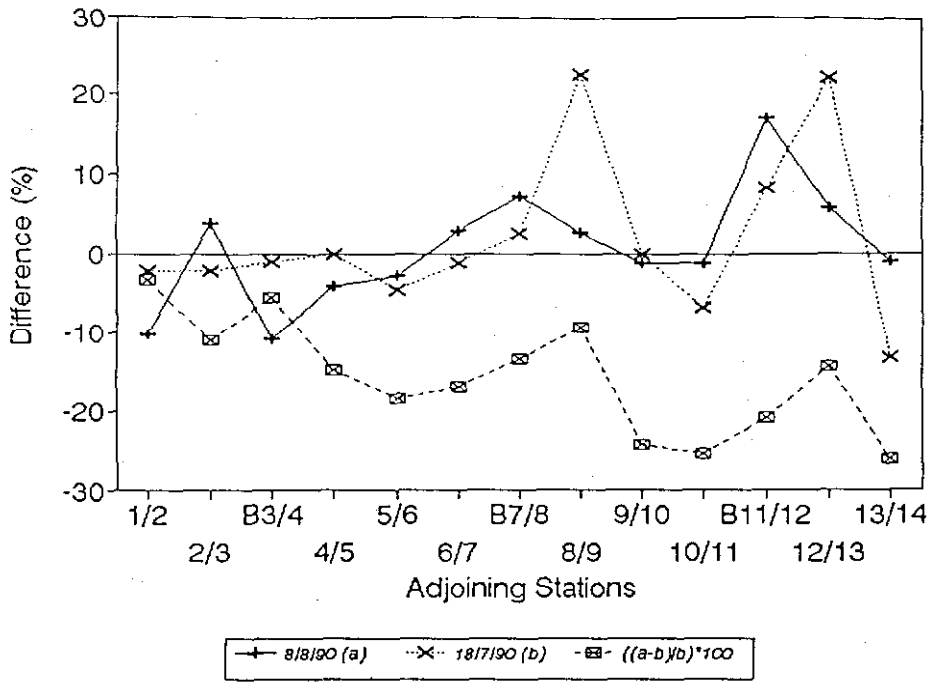


FIGURE 36a: Potassium: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

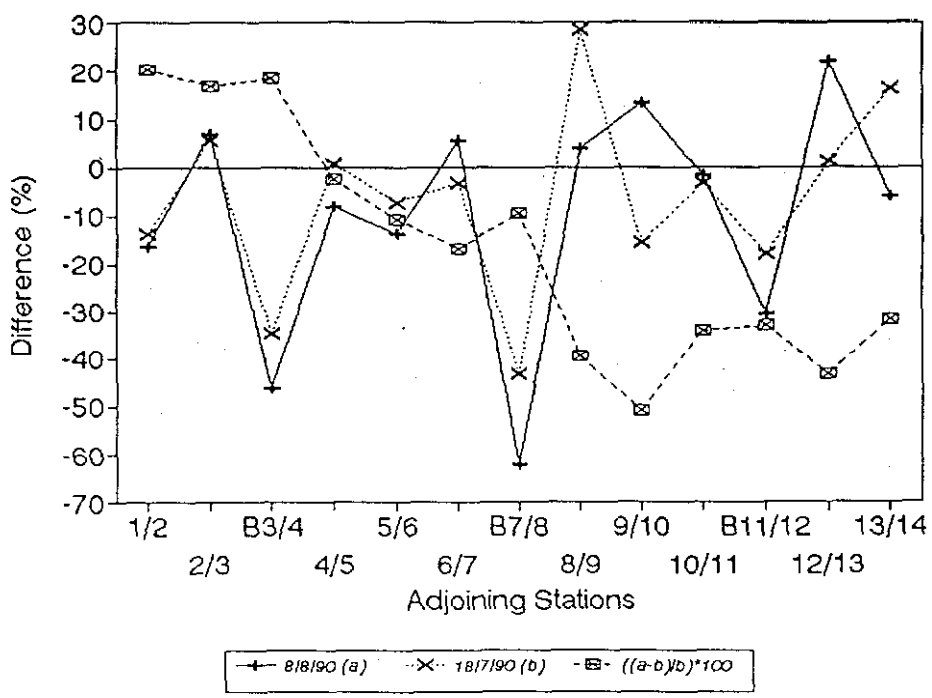


FIGURE 36b: Iron: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

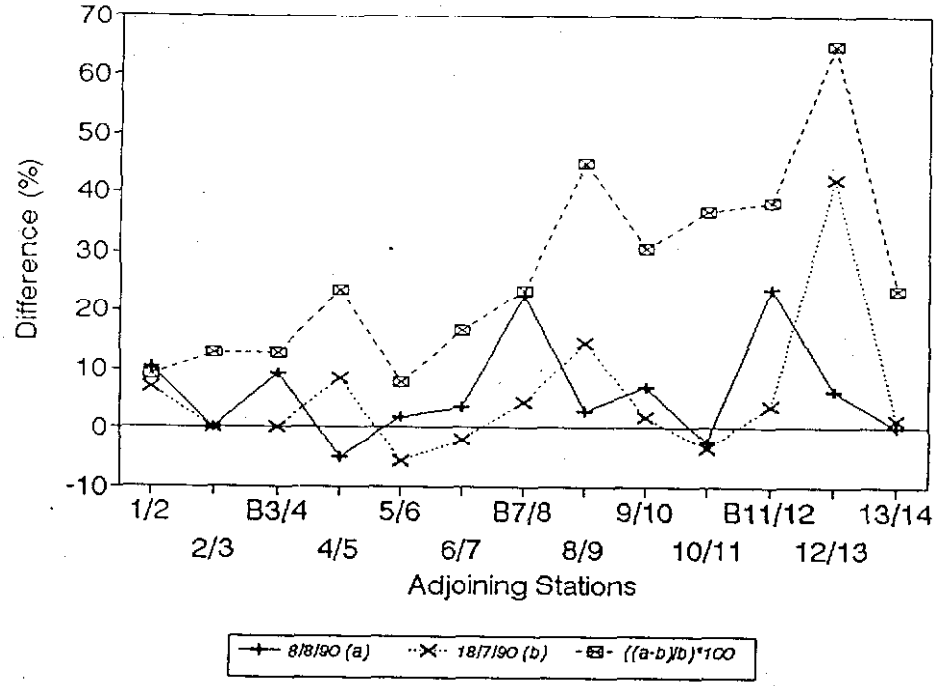


FIGURE 37a: Manganese: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

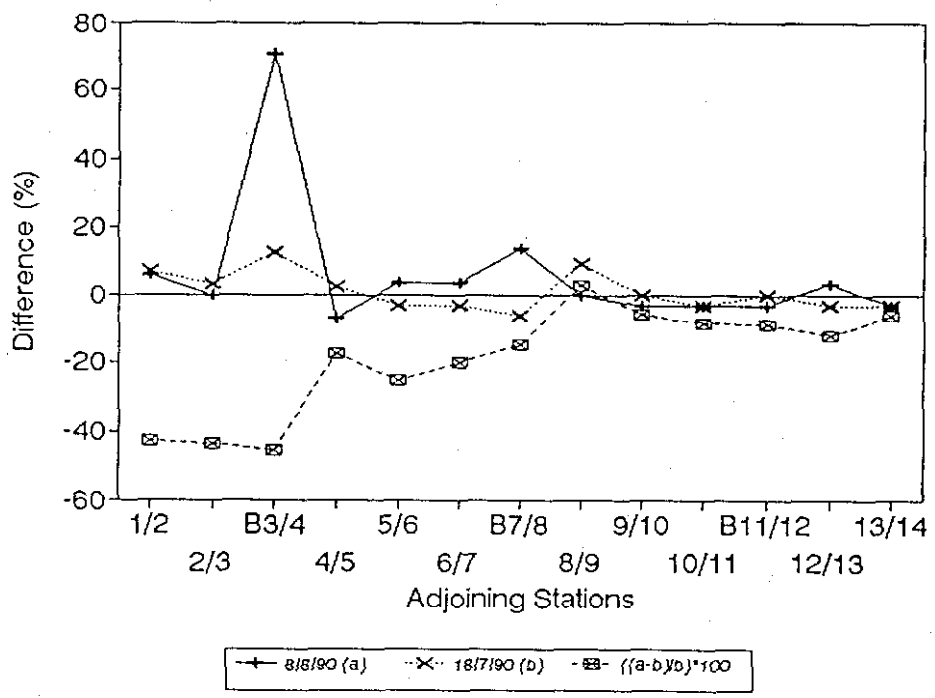


FIGURE 37b: Silica: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

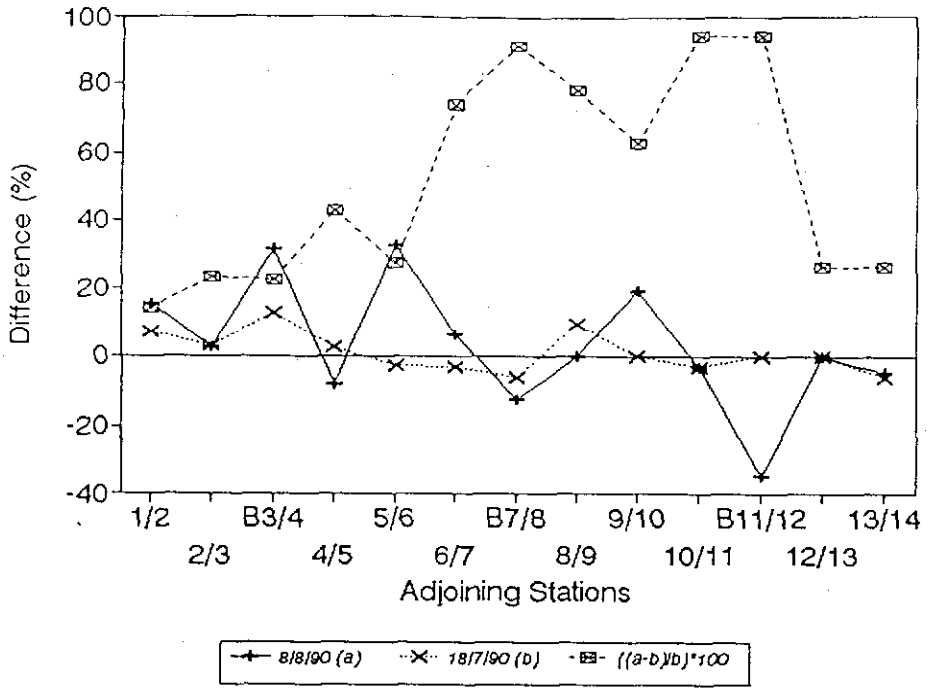


FIGURE 38a: Nickel: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

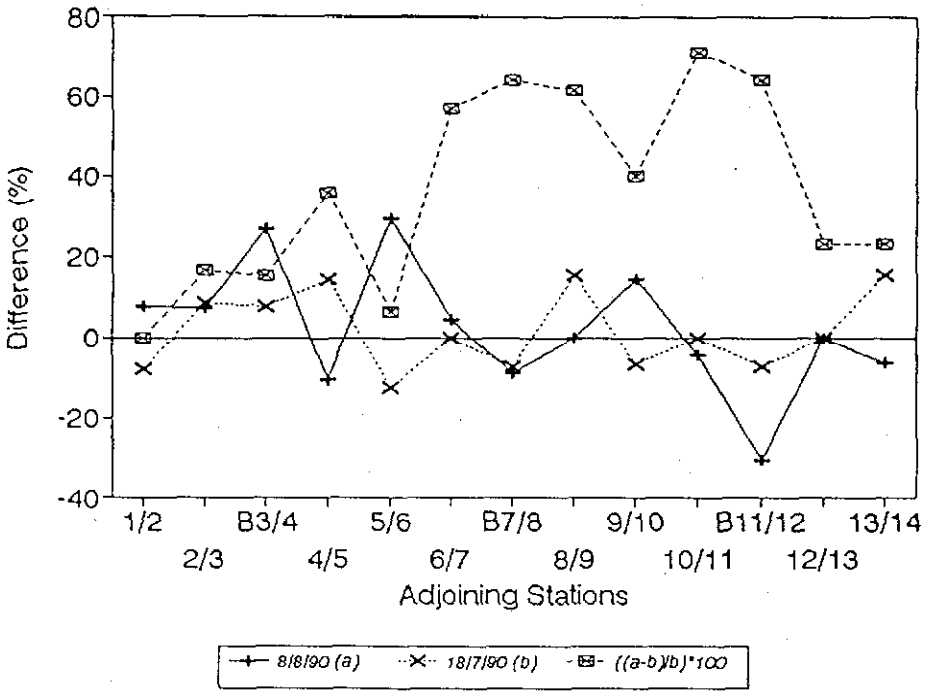


FIGURE 38b: Cobalt: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

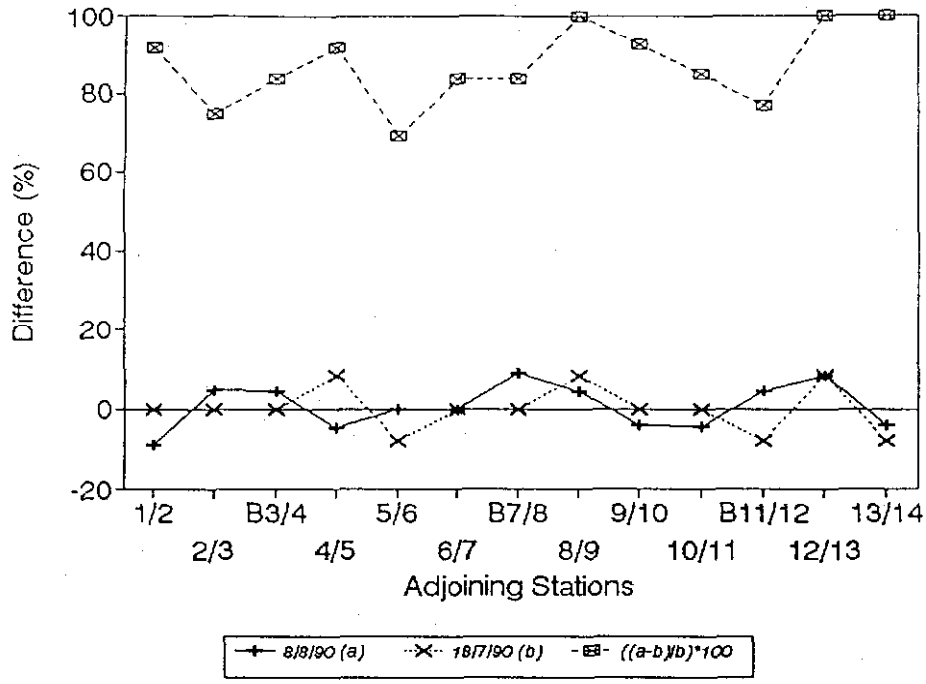


FIGURE 39a: Strontium: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

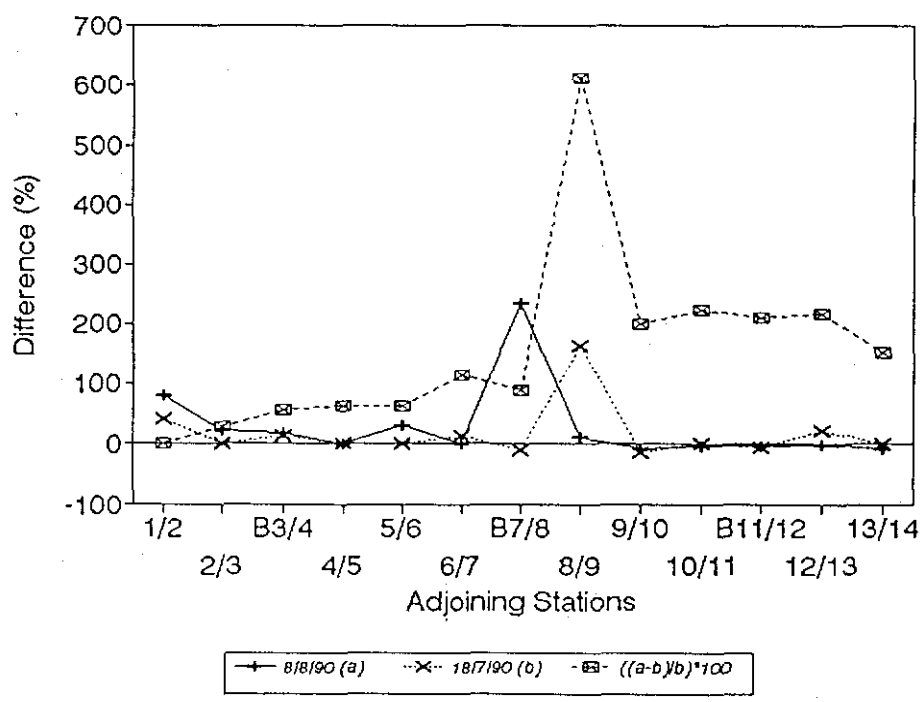


FIGURE 39b: Zinc: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

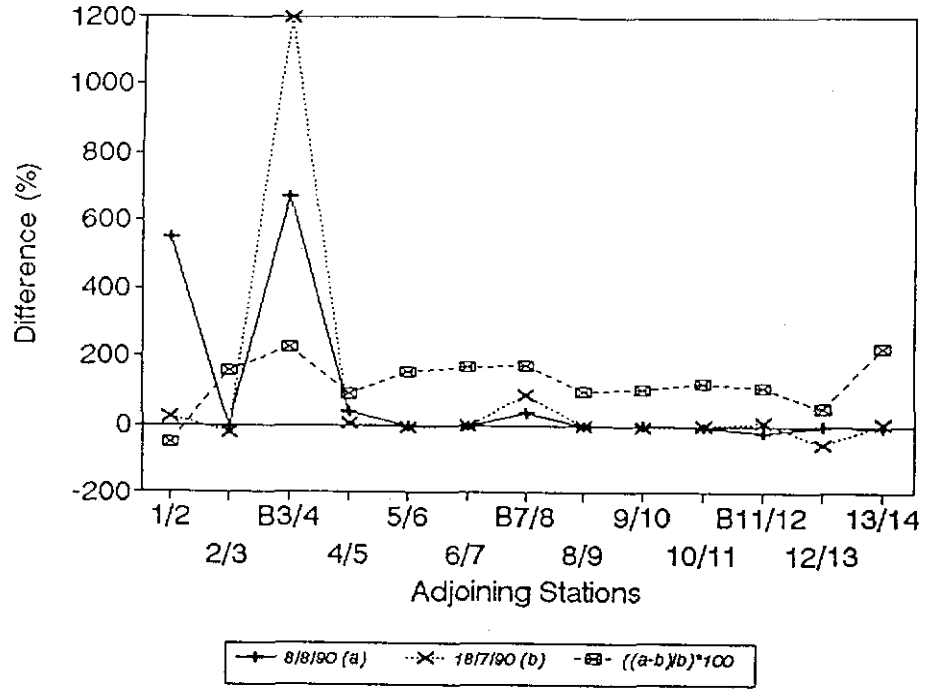


FIGURE 40a: Aluminum: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

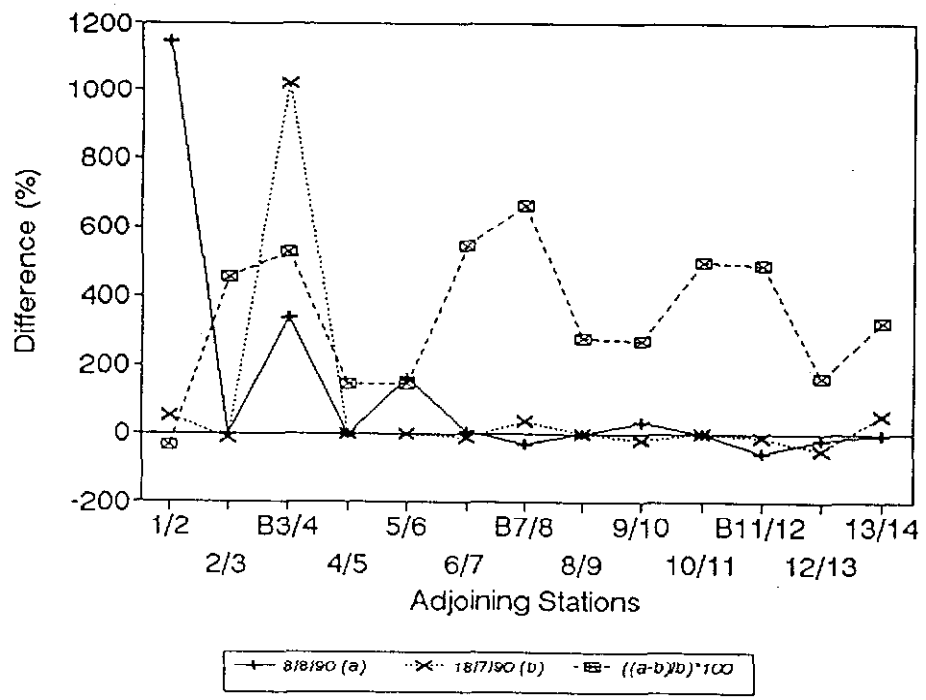
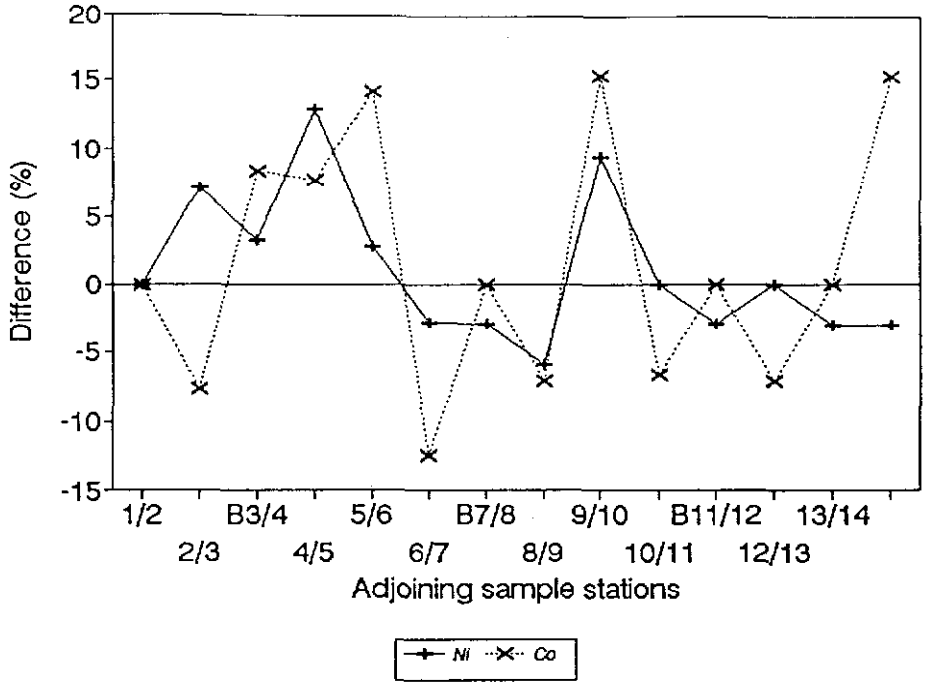


FIGURE 40b: Copper: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90



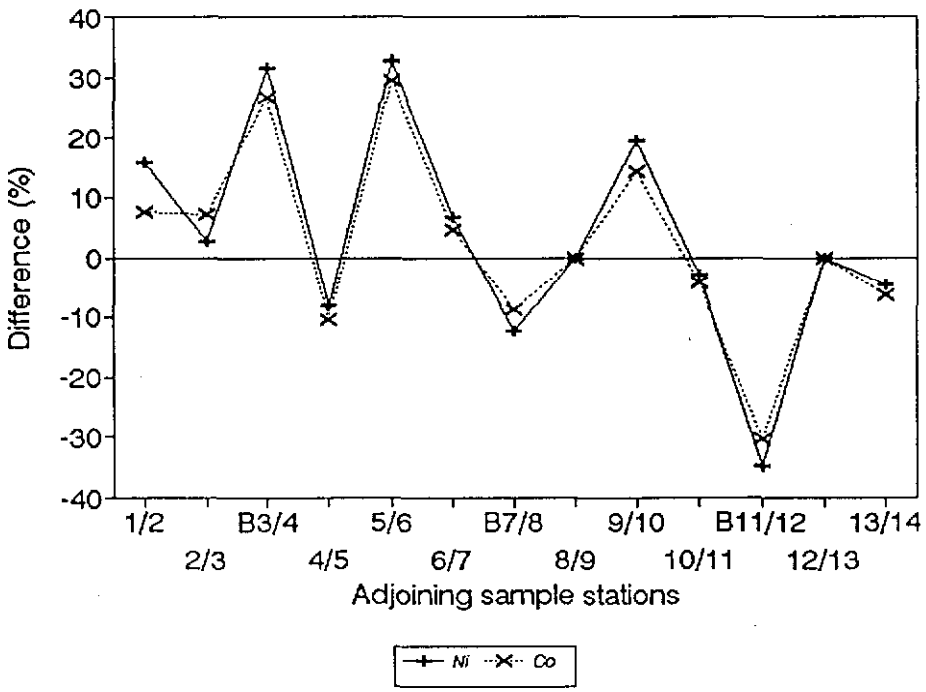
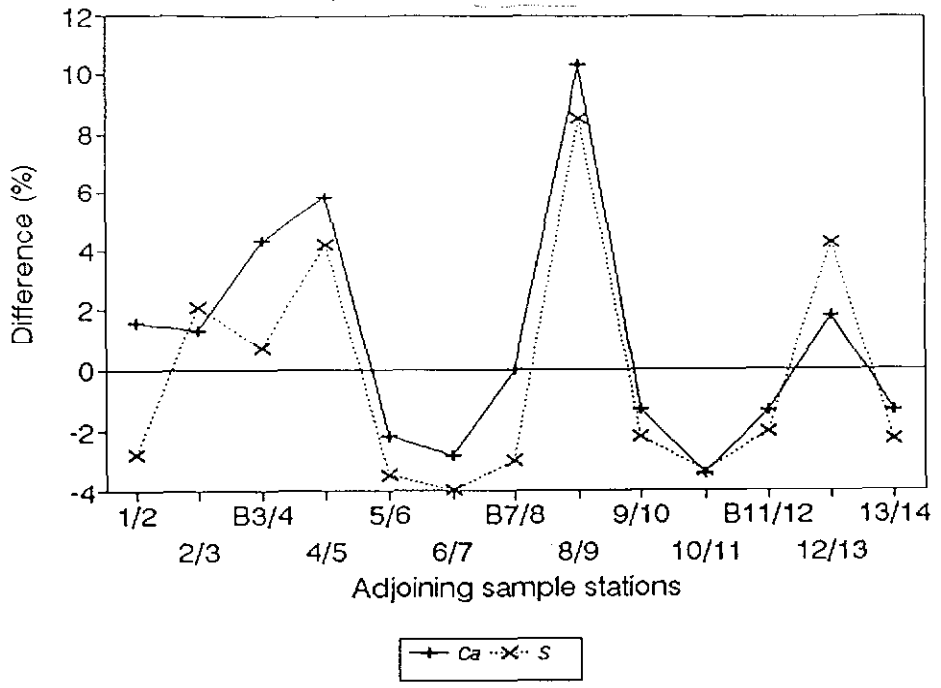


FIGURE 41: Copper/Nickel: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90



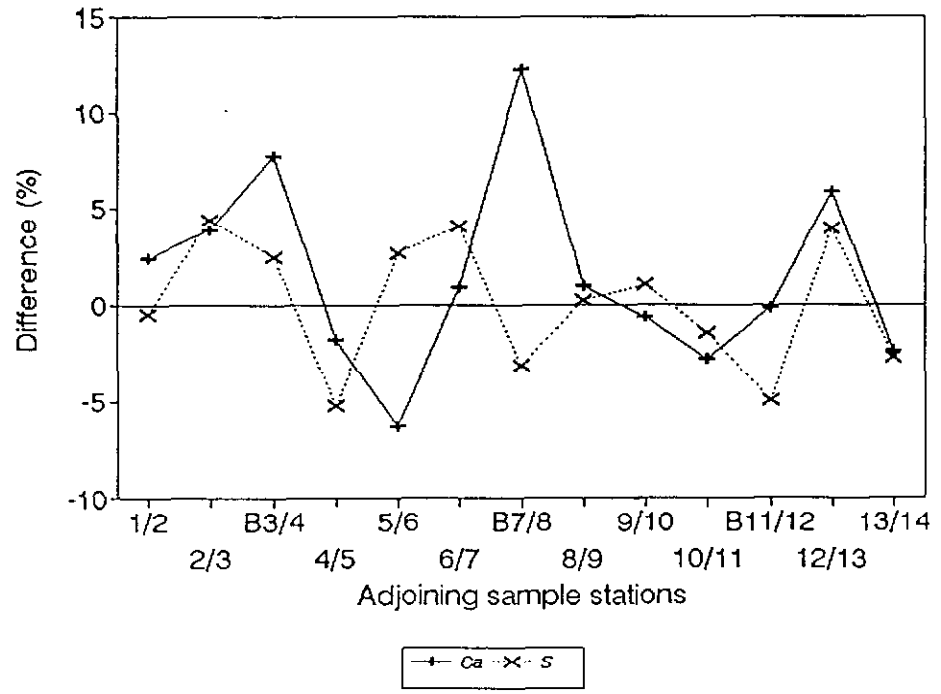


FIGURE 42: Calcium/Sulphur: Percentage Difference Between Adjoining Stations: 18/07/90 & 08/08/90

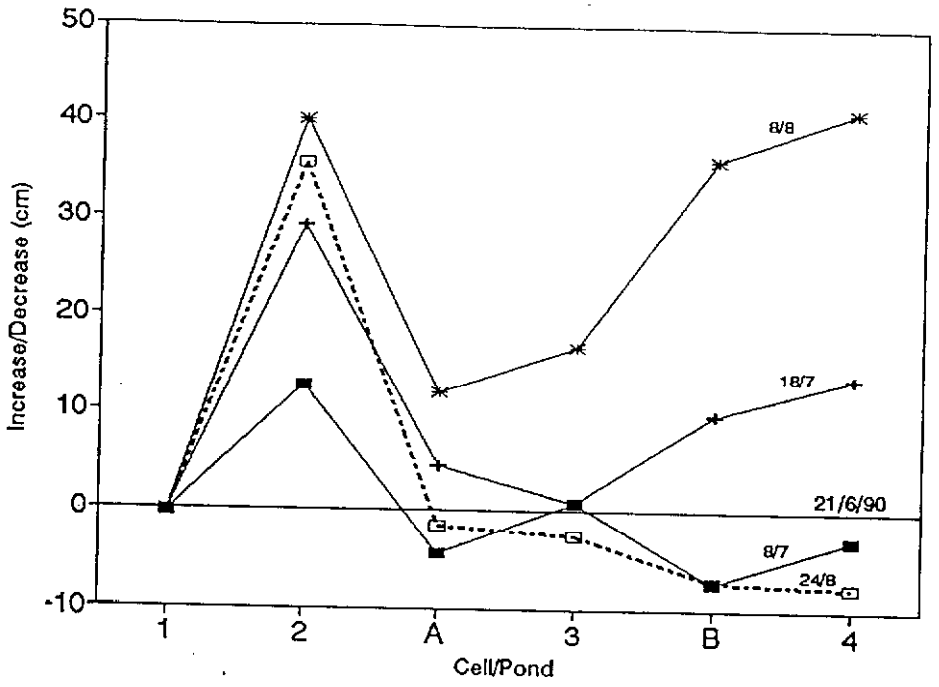
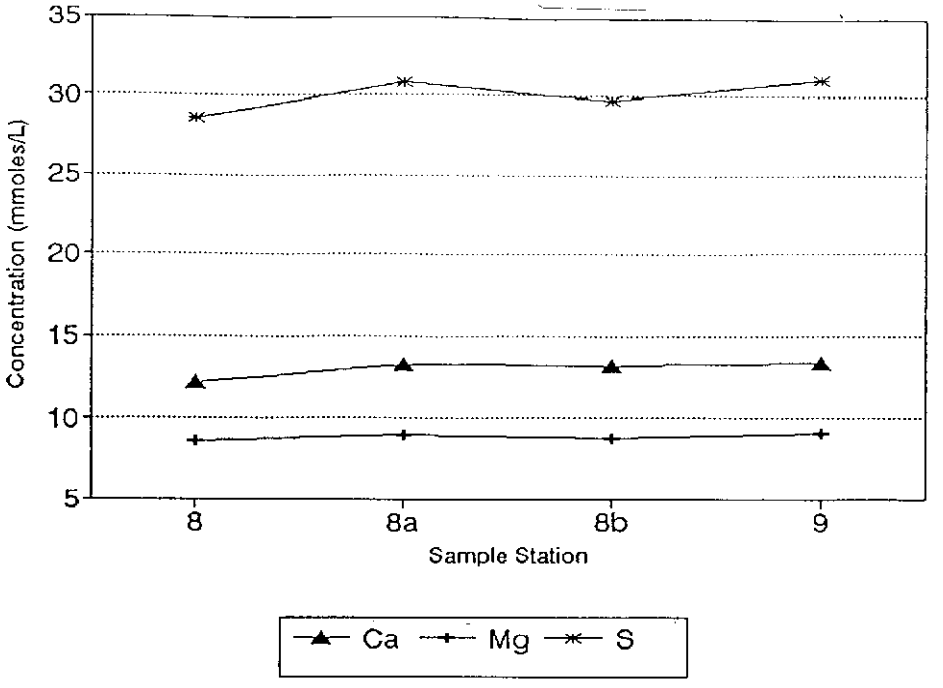


FIGURE 43: Increase/Decrease in Water Levels in Cells and Ponds



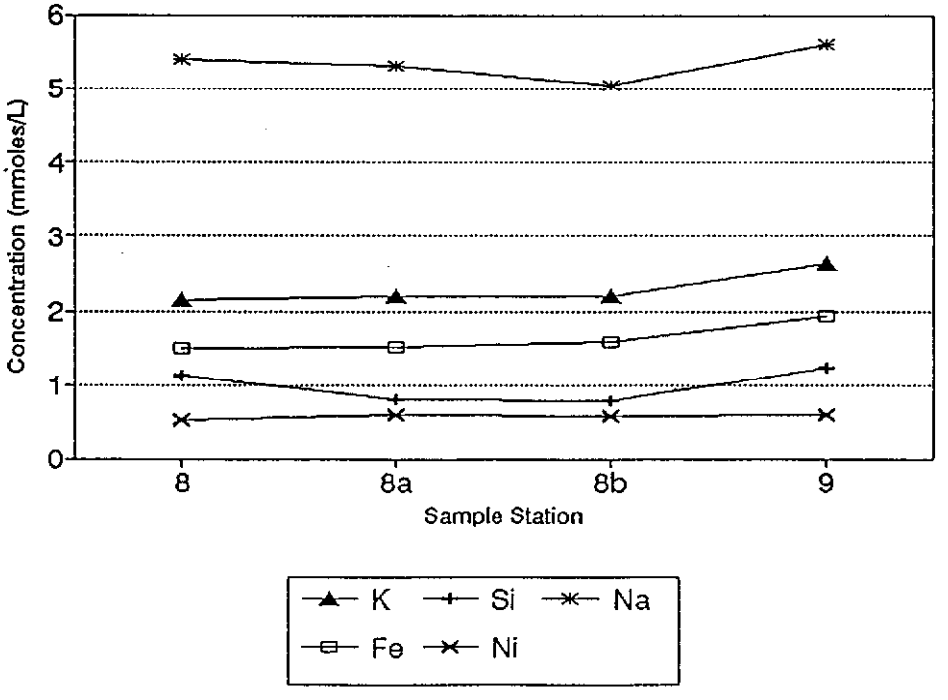


FIGURE 44: Changes in Concentration Within Cell 3: Ca, Mg, S, K, Si, Na, Fe and Ni

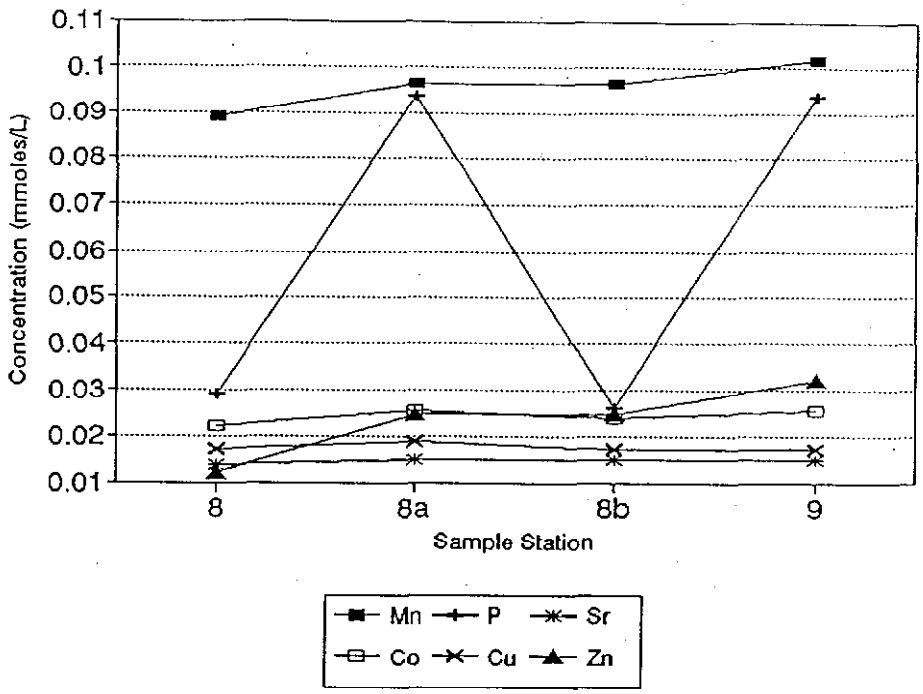


FIGURE 45: Changes in Concentration Within Cell 3: Mn, P, Sr, Co, Cu and Zn

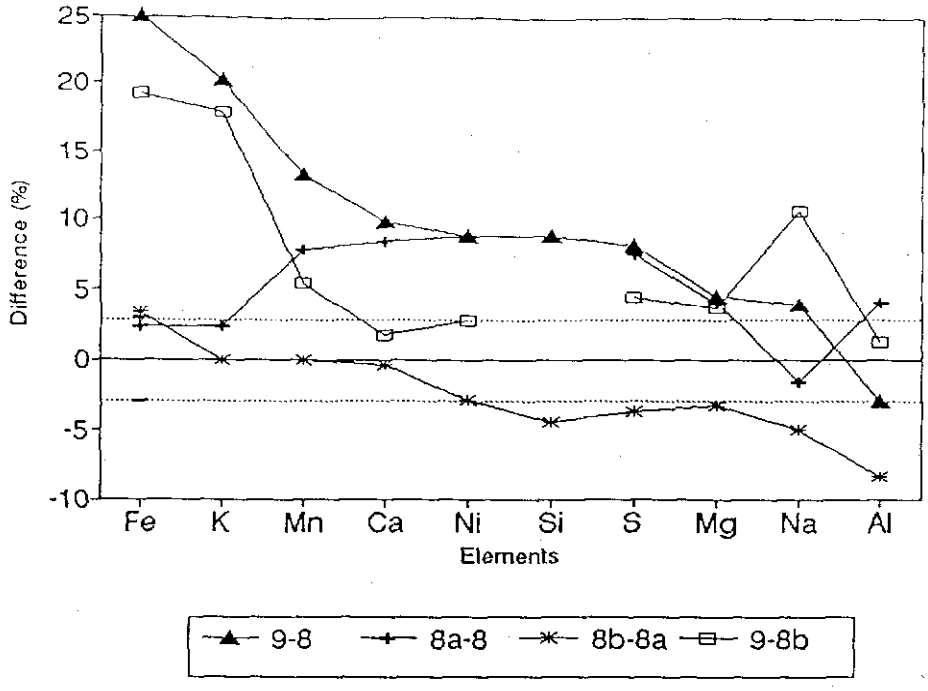


FIGURE 46a: Percent Difference Between STNs 8, 8a, 8b and 9: Cell 3, 18/07/90

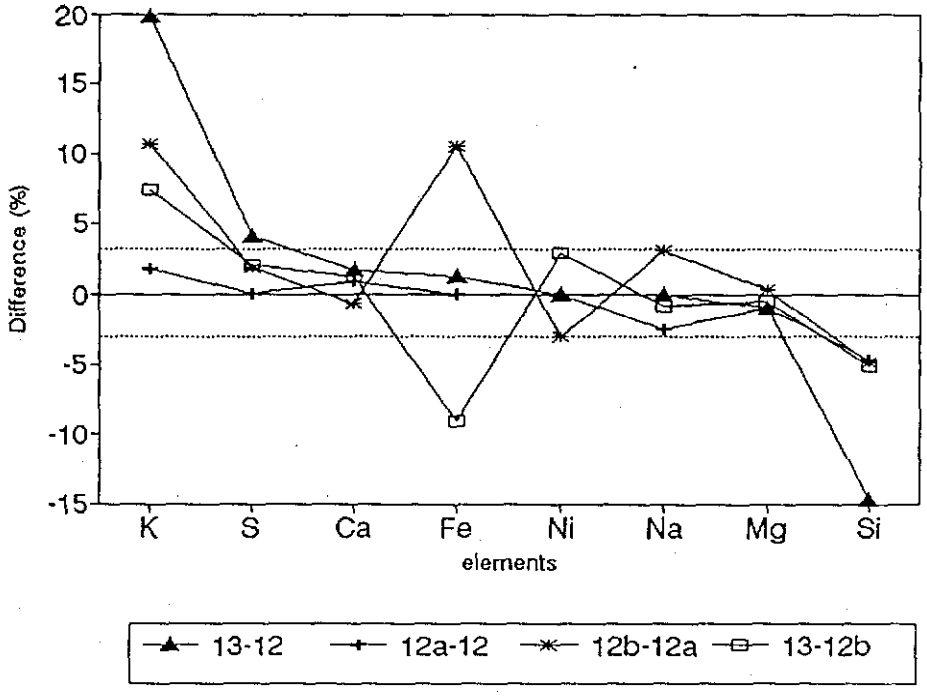


FIGURE 46b: Percent Difference Between STNs 12, 12a, 12b and 13: Cell 4, 18/07/90

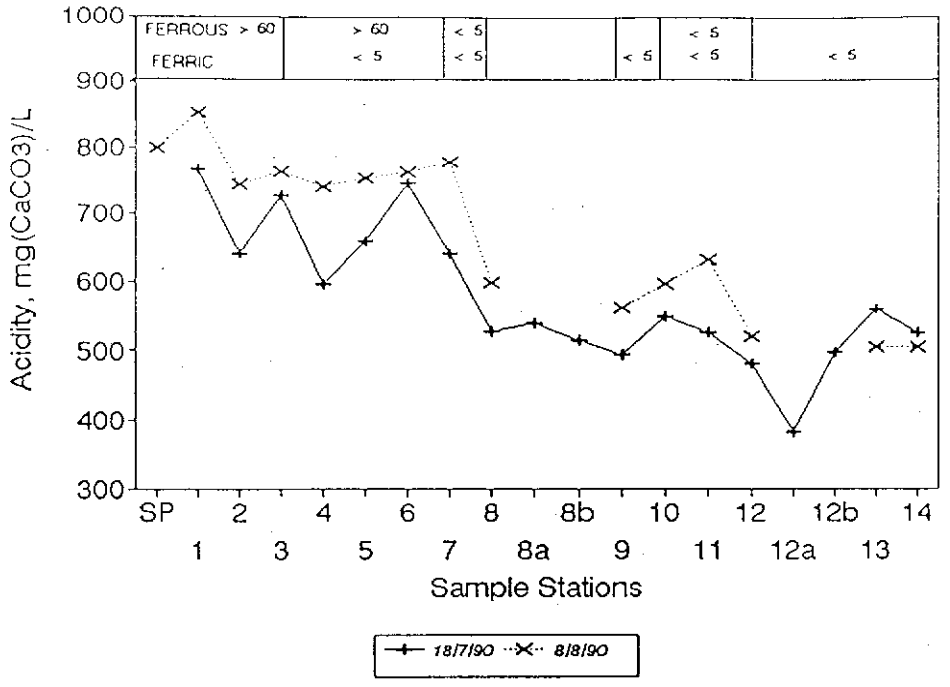


FIGURE 47a: Acidity in Cells and Ferrous/Ferric Field Measurements: 18/07/90 and 08/08/90

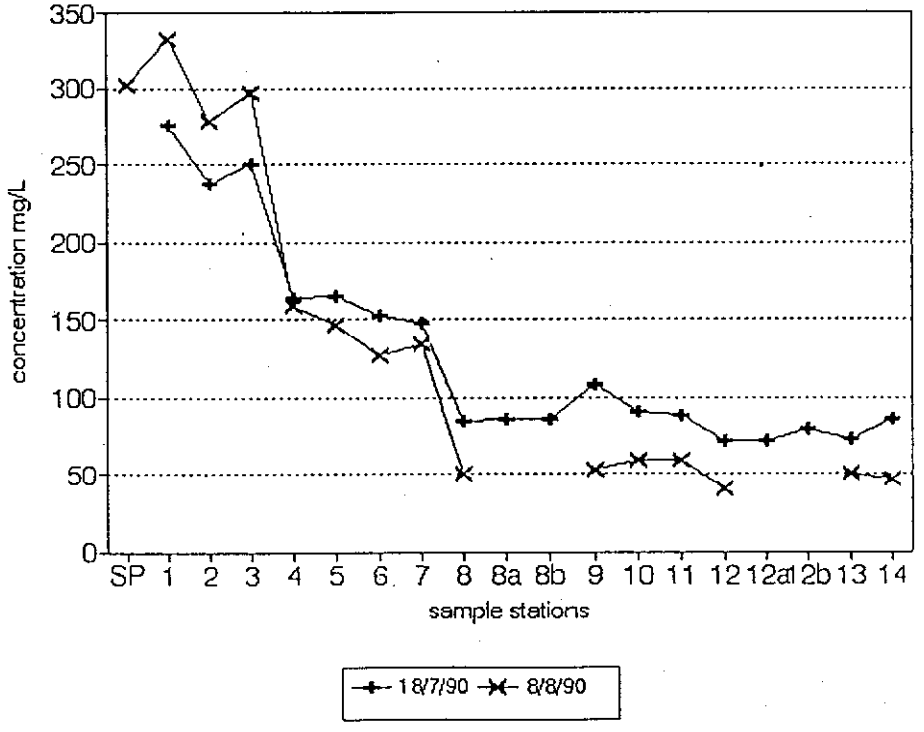


Figure 47b: Iron in Cells: 18/07/90 and 08/08/90

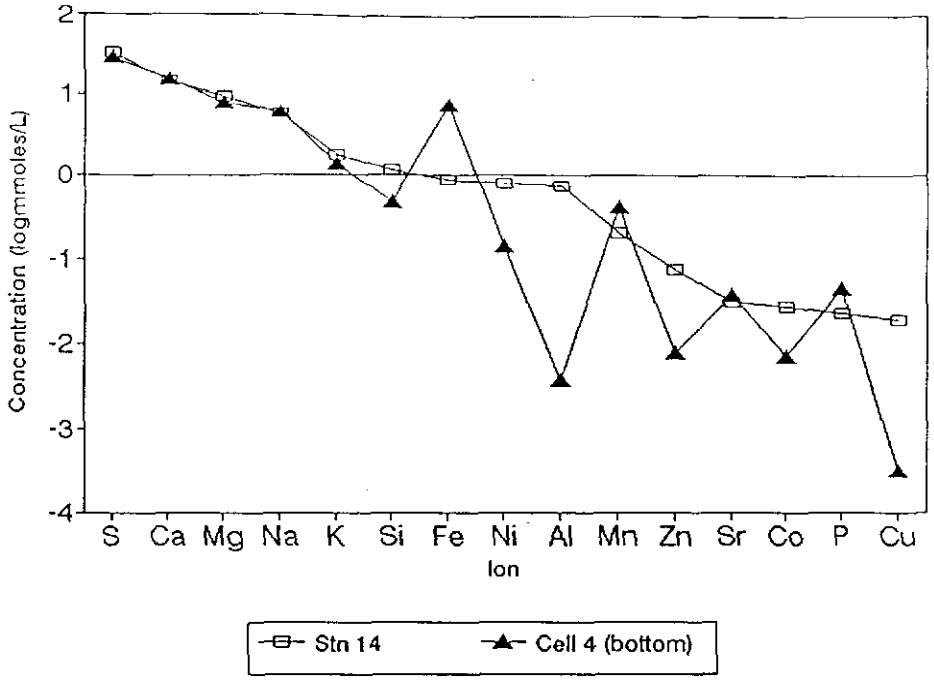


FIGURE 48a: Ion Concentration in Cell 4 (bottom) and STN 14, 24/08/90

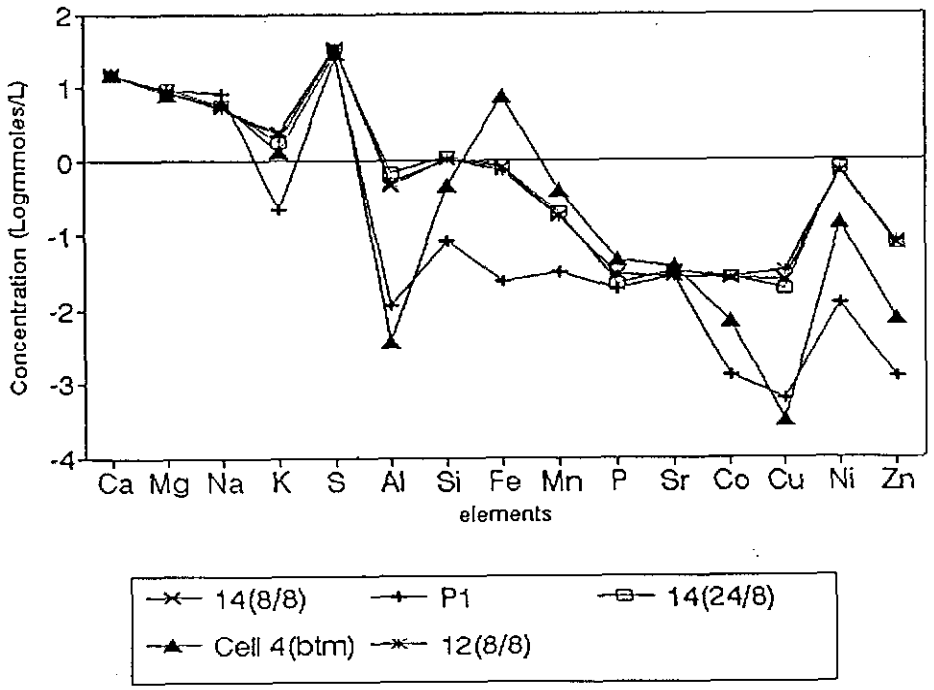


FIGURE 48b: Ion Concentration in Cell 4 (bottom), STN 14 (08/08/90), STN 14 (24/08/90) and P-1

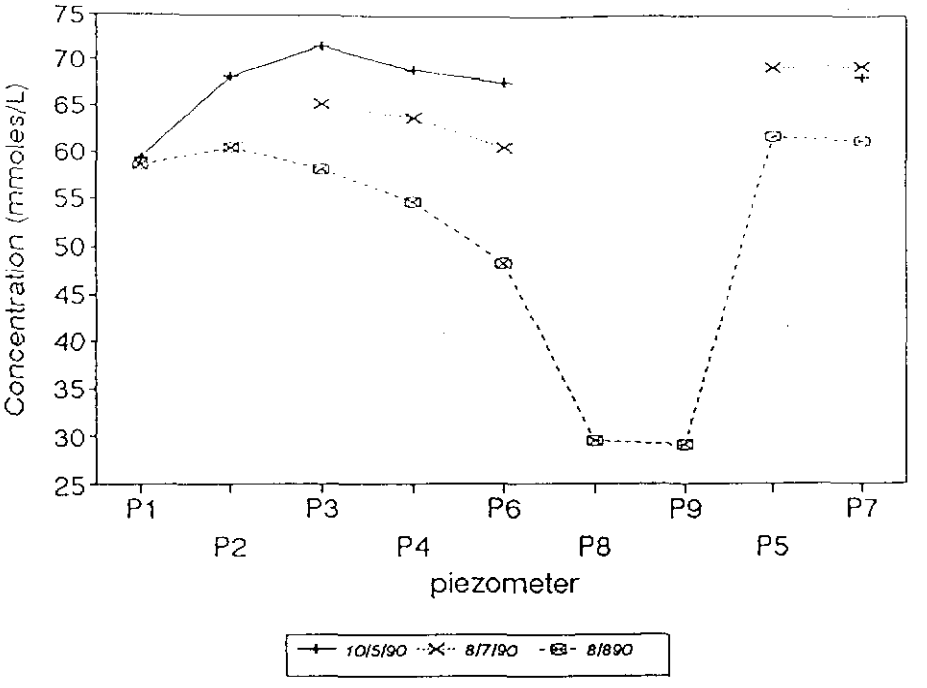


FIGURE 49a: Total Ion Concentration in Piezometers

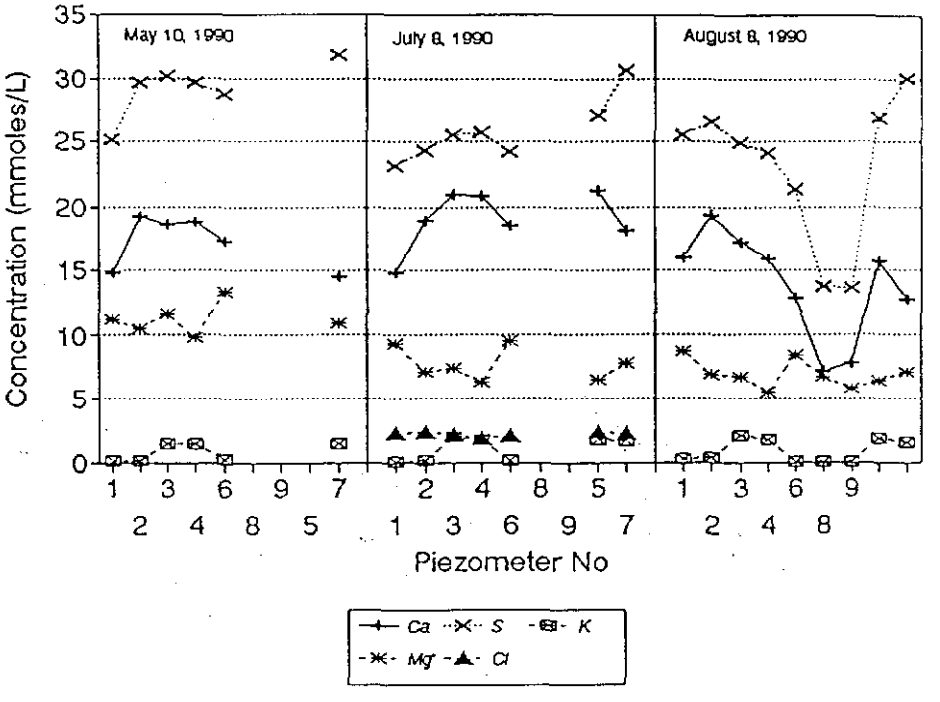


FIGURE 49b: Concentration of Major Ions in Piezometers

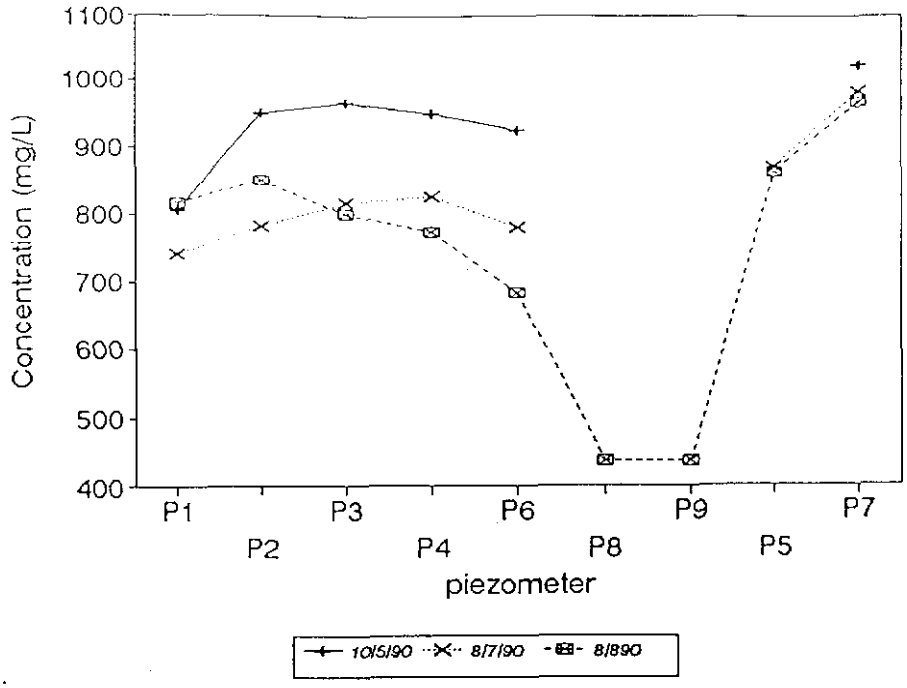


FIGURE 50a: Concentration of Sulphur in Piezometers

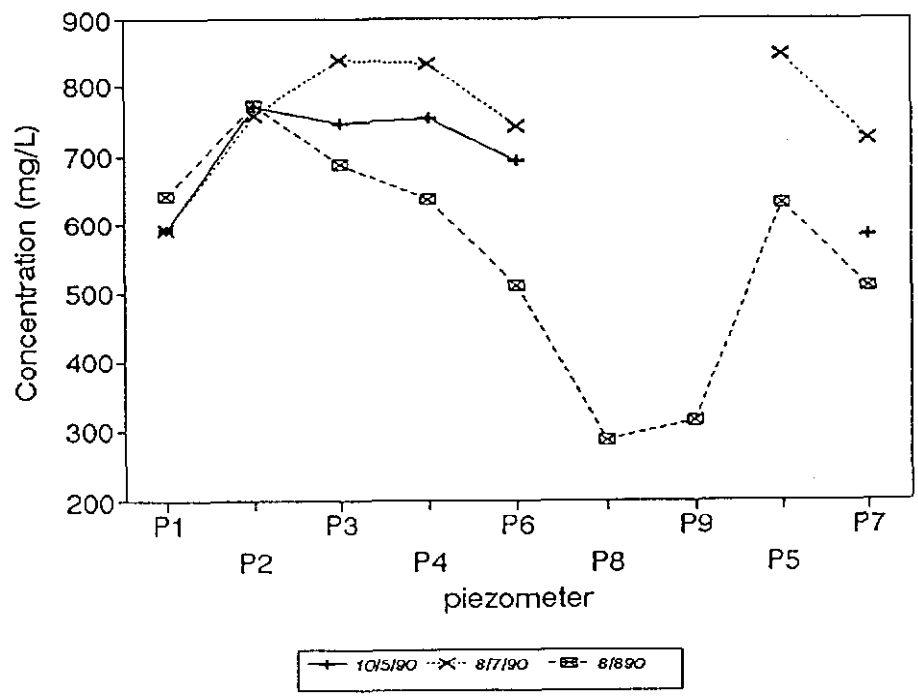


FIGURE 50b: Concentration of Calcium in Piezometers

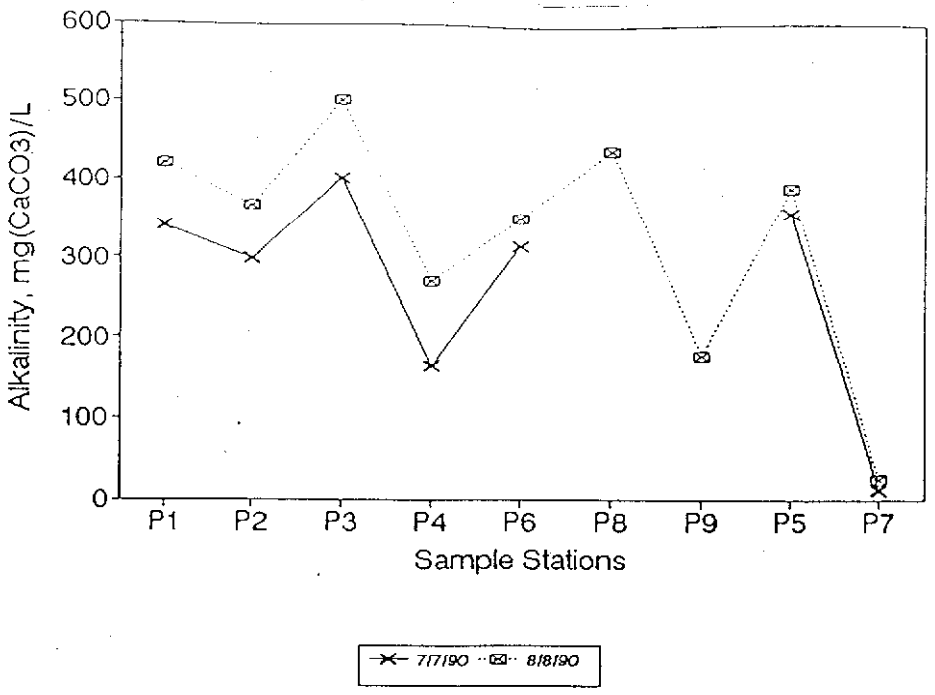


FIGURE 51a: Concentration of Alkalinity in Piezometers

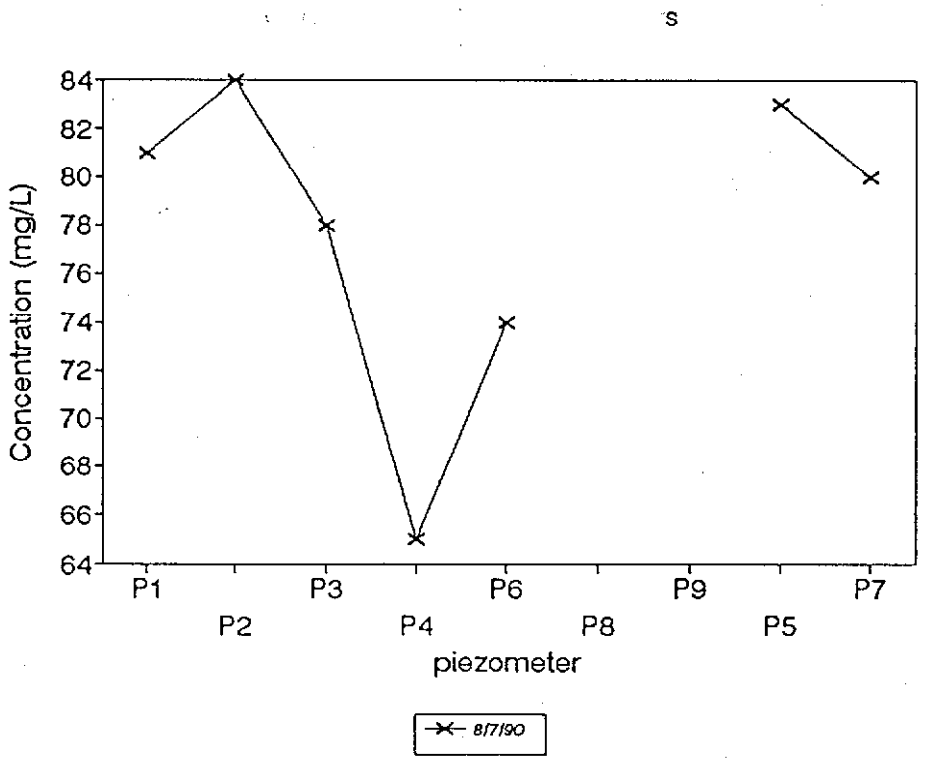


FIGURE 51b: Concentration of Chloride in Piezometers

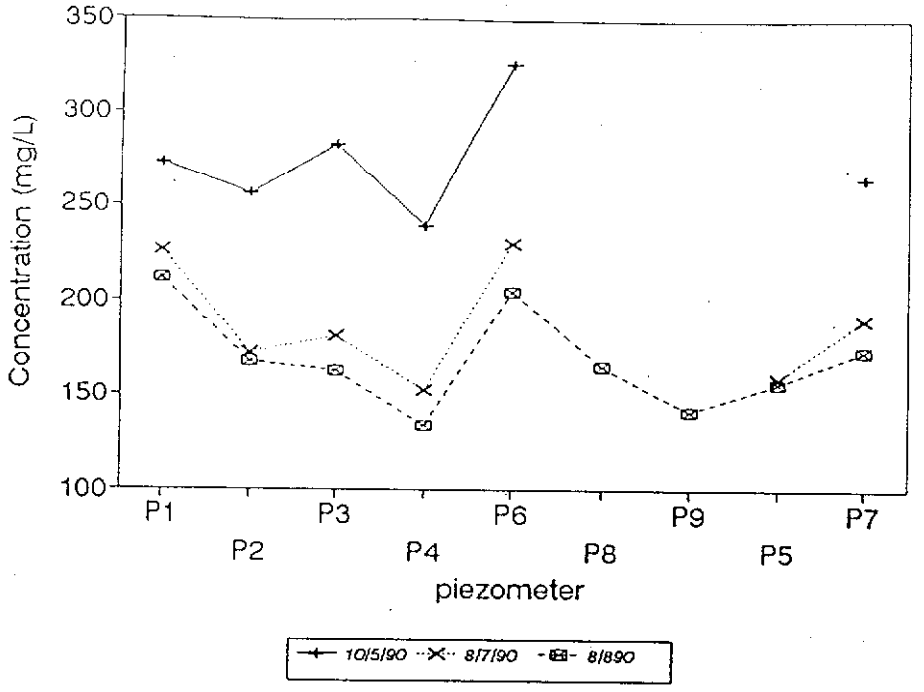


FIGURE 52a: Concentration of Magnesium in Piezometers

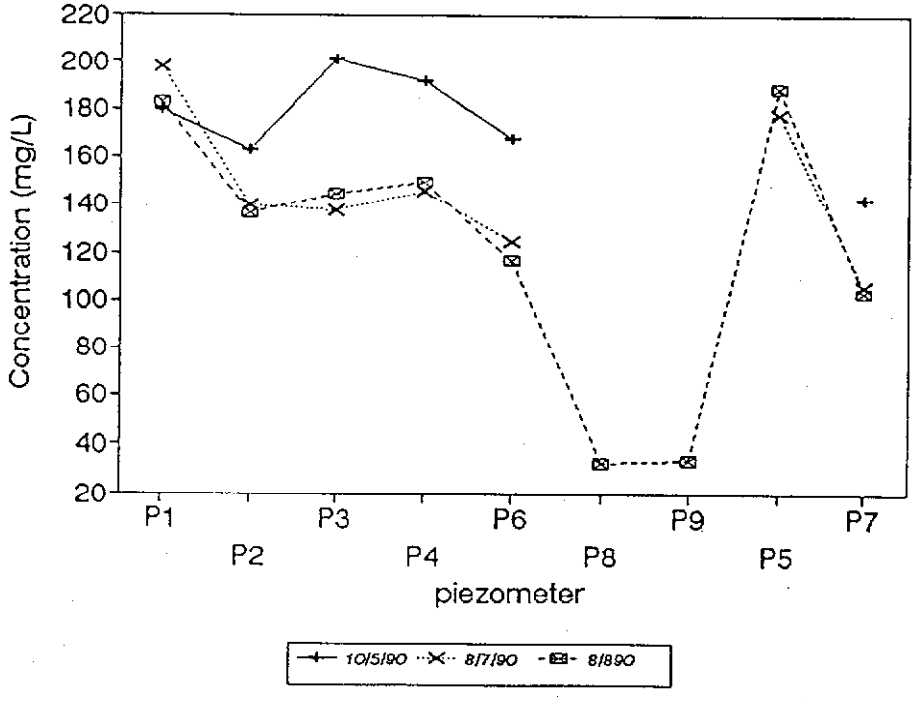


FIGURE 52b: Concentration of Sodium in Piezometers

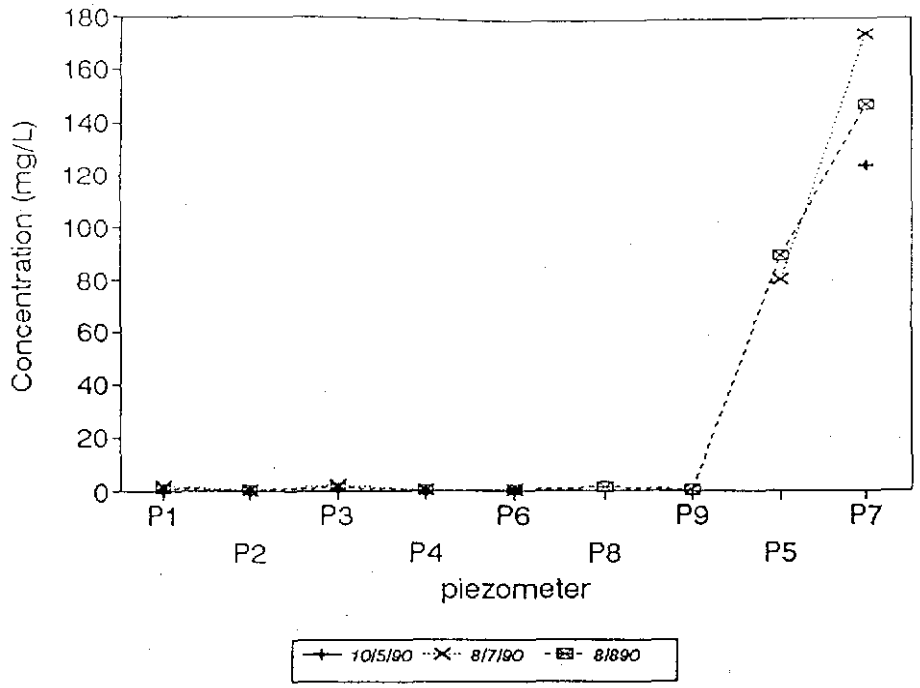


FIGURE 53a: Concentration of Iron in Piezometers

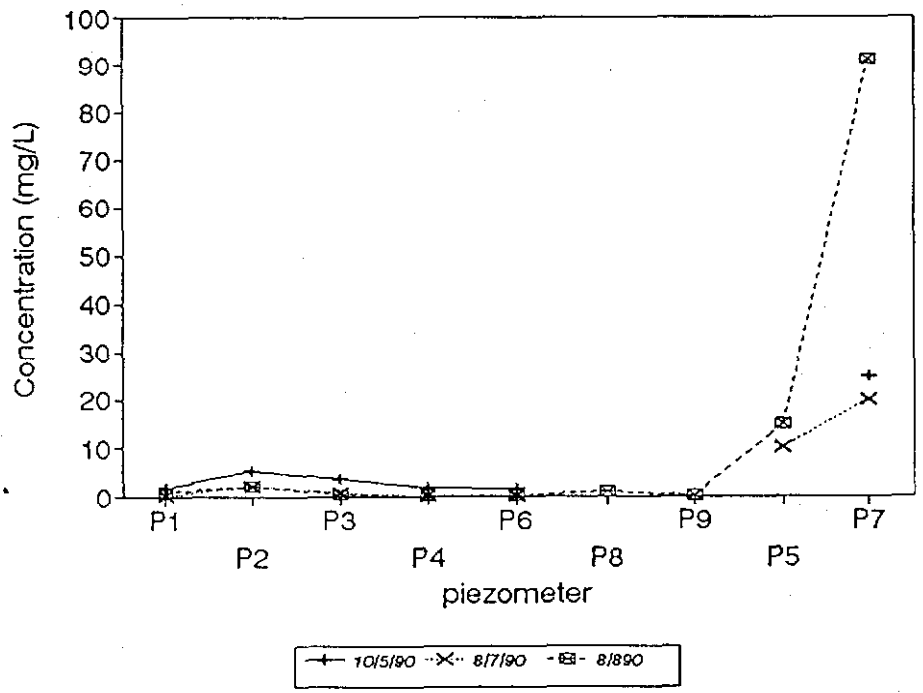


FIGURE 53b: Concentration of Nickel in Piezometers

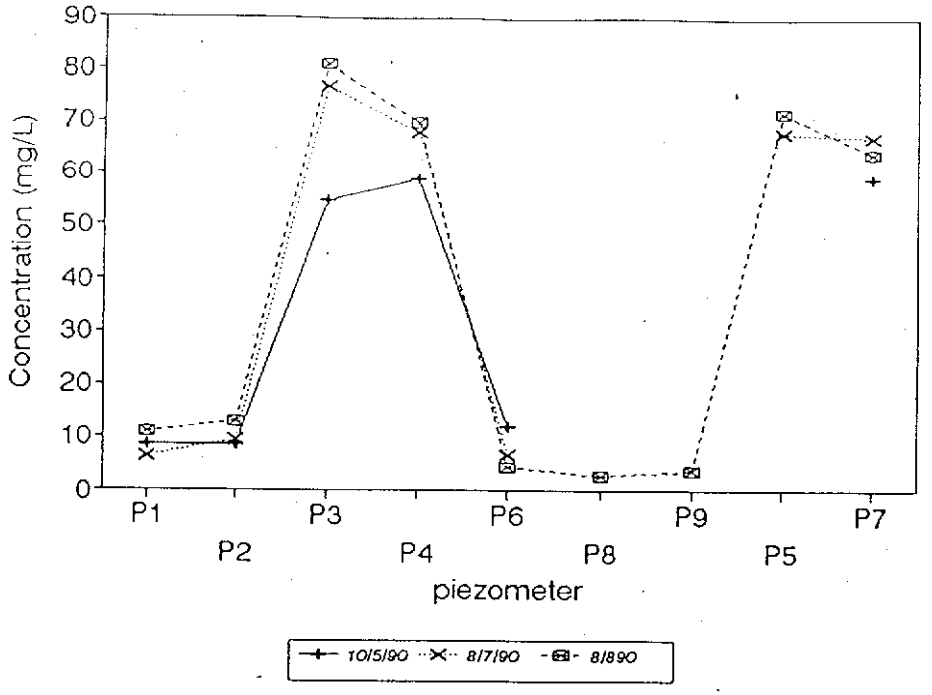


FIGURE 54a: Concentration of Potassium in Piezometers

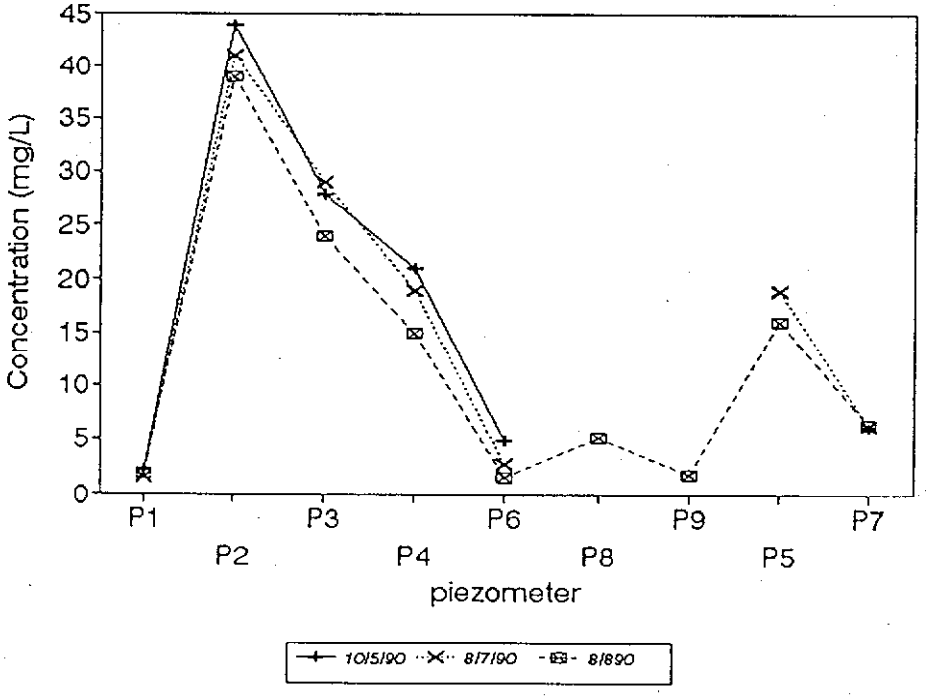


FIGURE 54b: Concentration of Manganese in Piezometers

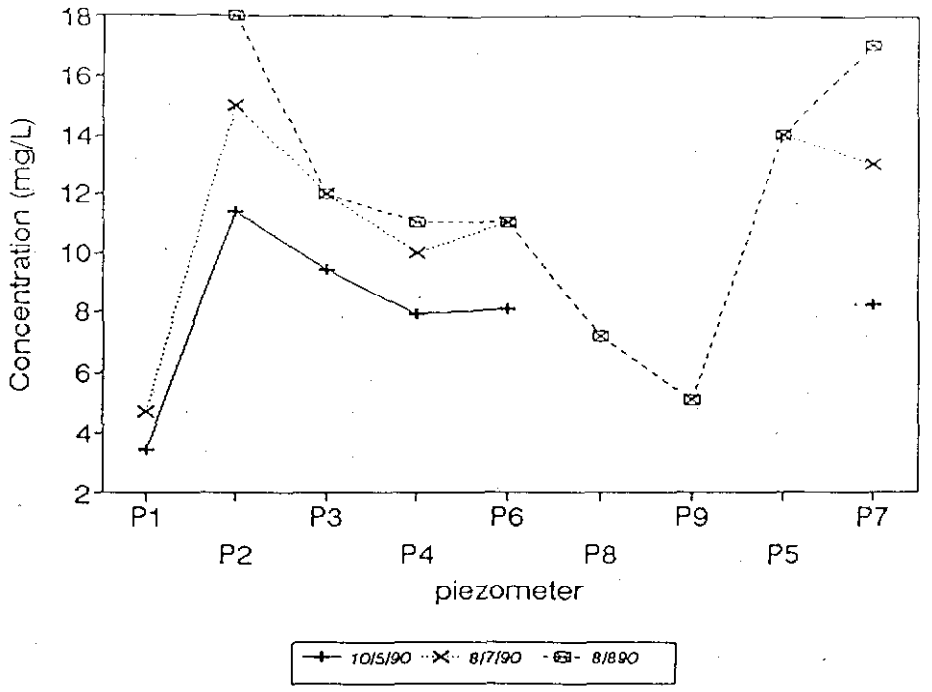


FIGURE 55a: Concentration of Silica in Piezometers

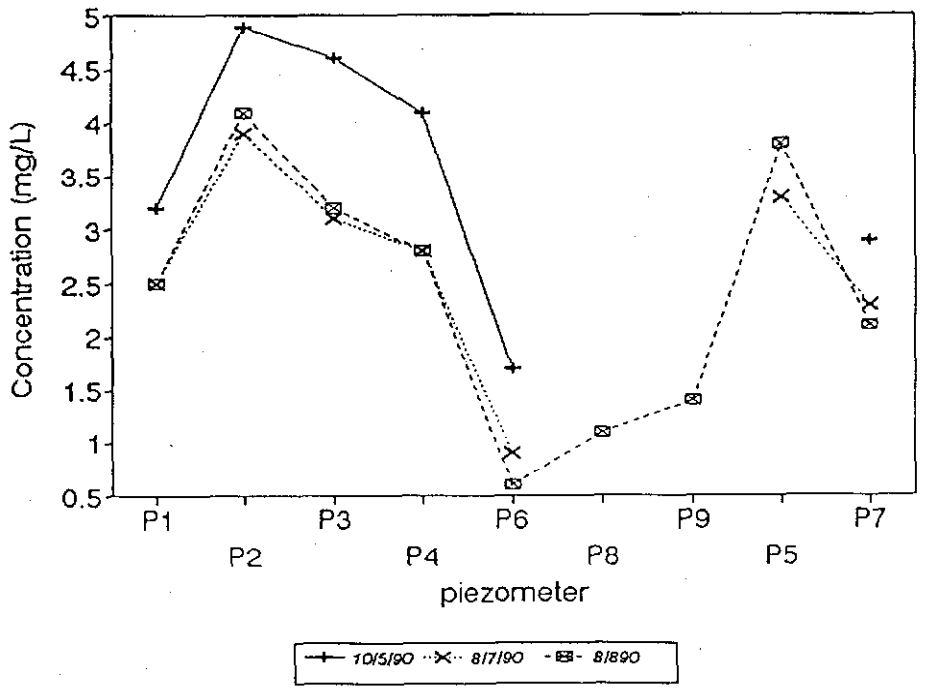


FIGURE 55b: Concentration of Strontium in Piezometers

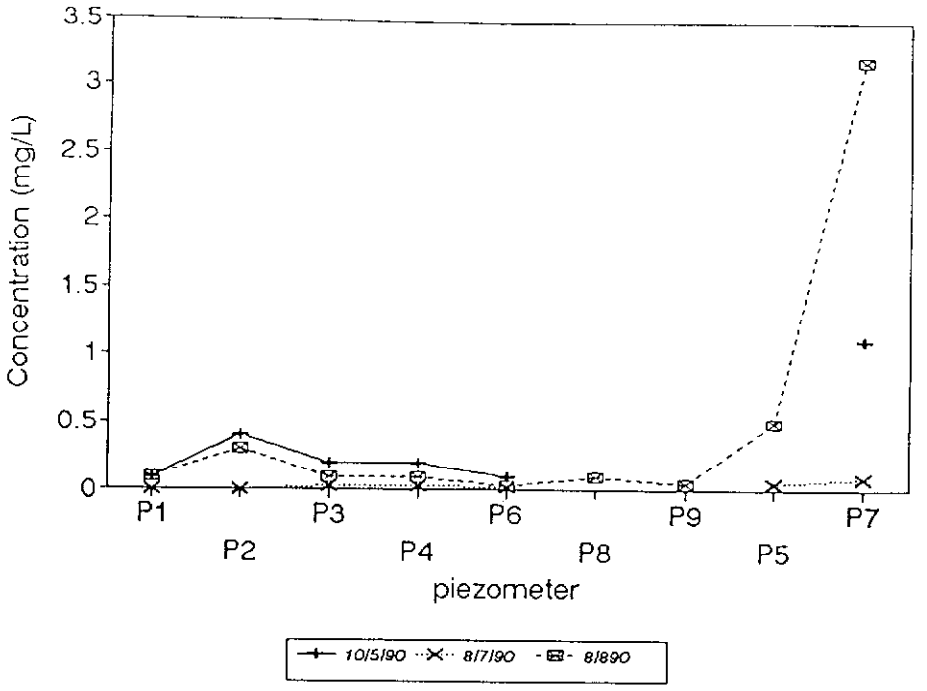


FIGURE 56a: Concentration of Cobalt in Piezometers

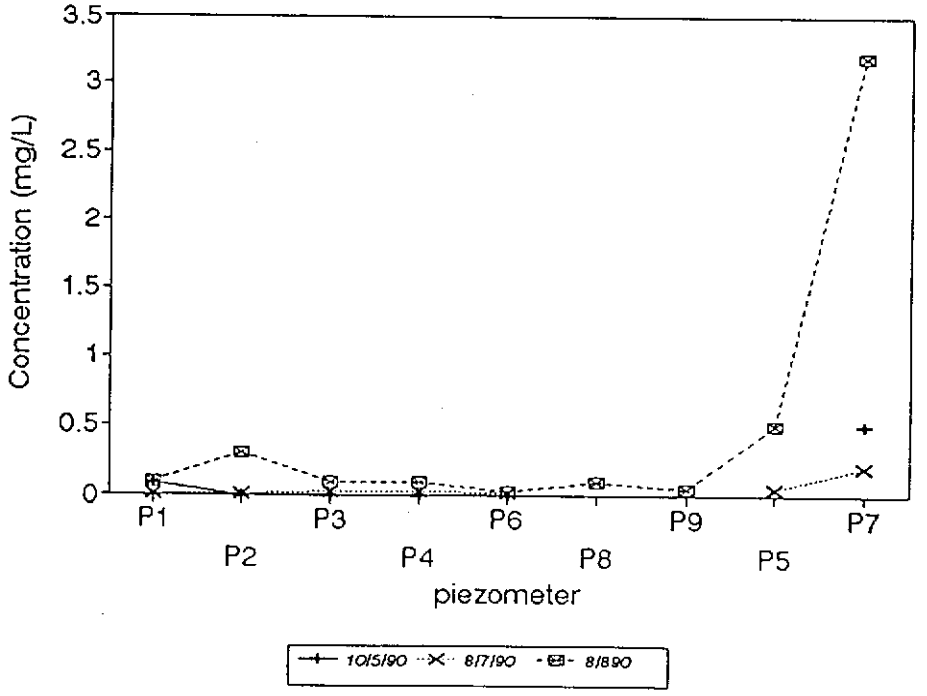


FIGURE 56b: Concentration of Copper in Piezometers

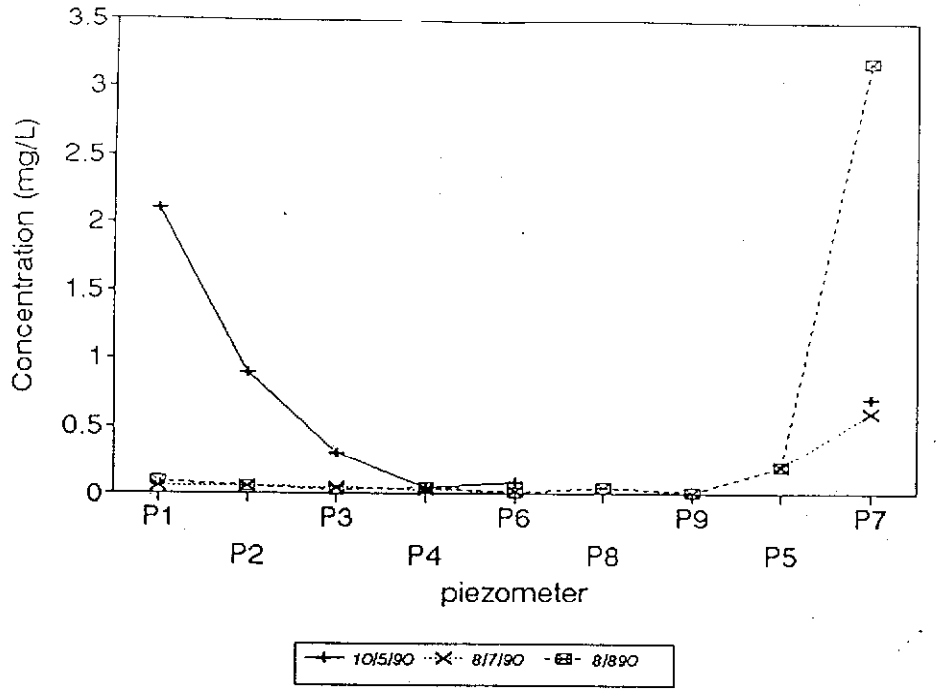


FIGURE 57a: Concentration of Zinc in Piezometers

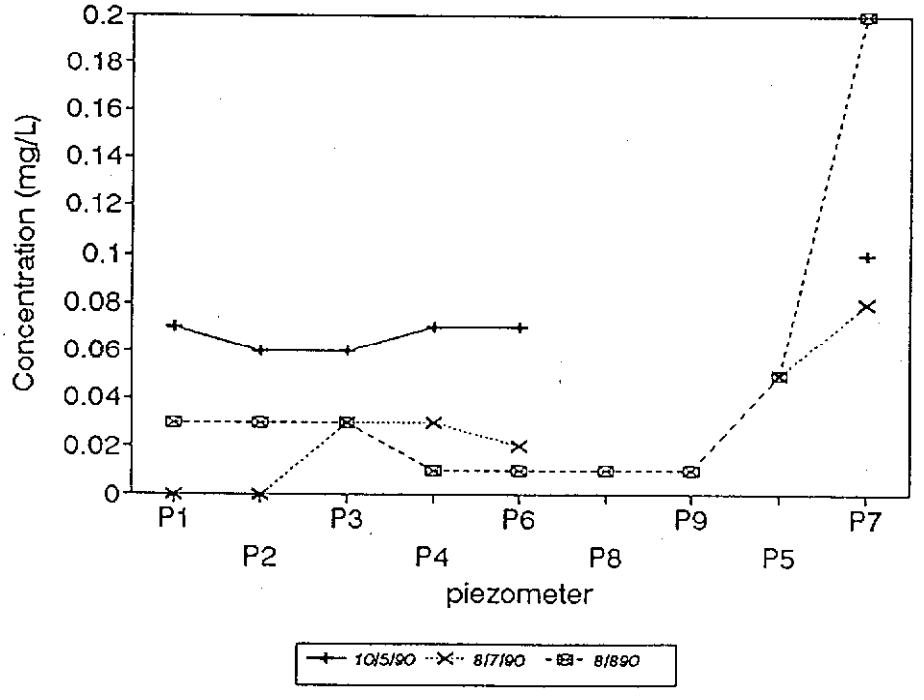


FIGURE 57b: Concentration of Cadmium in Piezometers

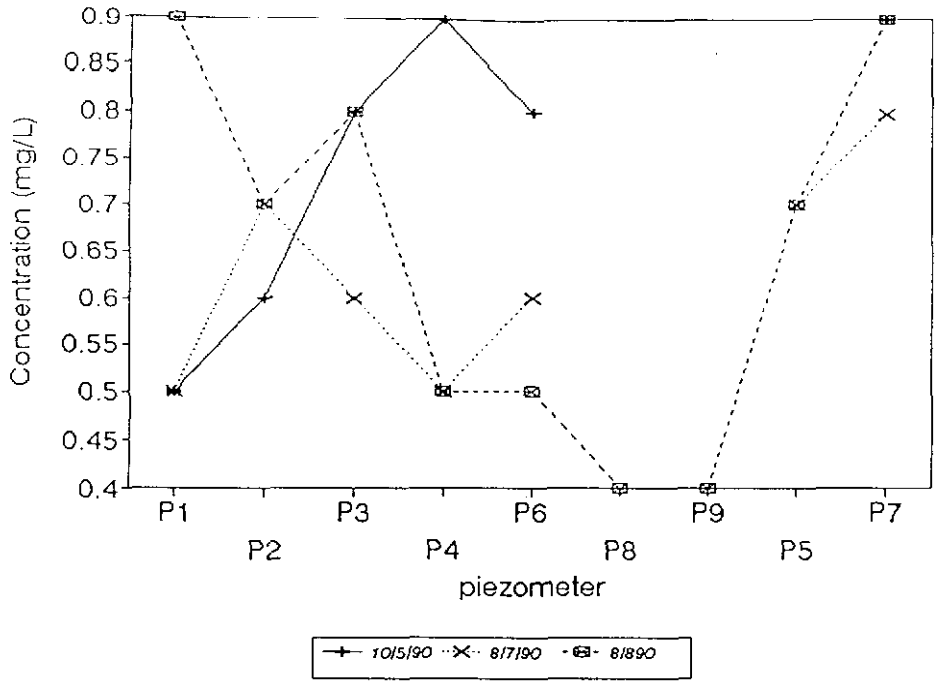


FIGURE 58a: Concentration of Phosphorus in Piezometers

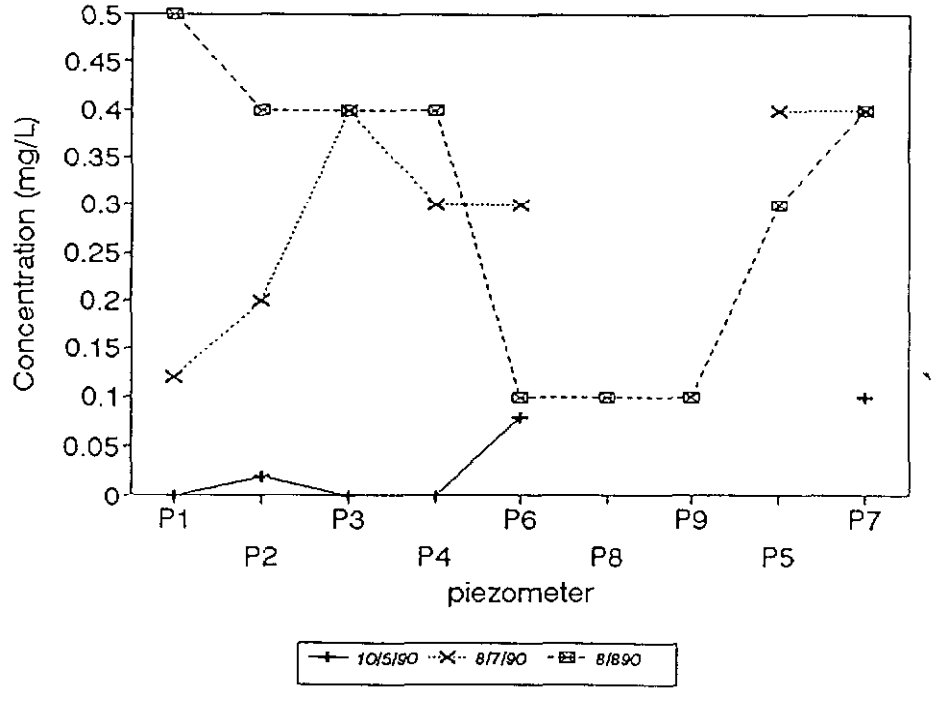


FIGURE 58b: Concentration of Aluminum in Piezometers

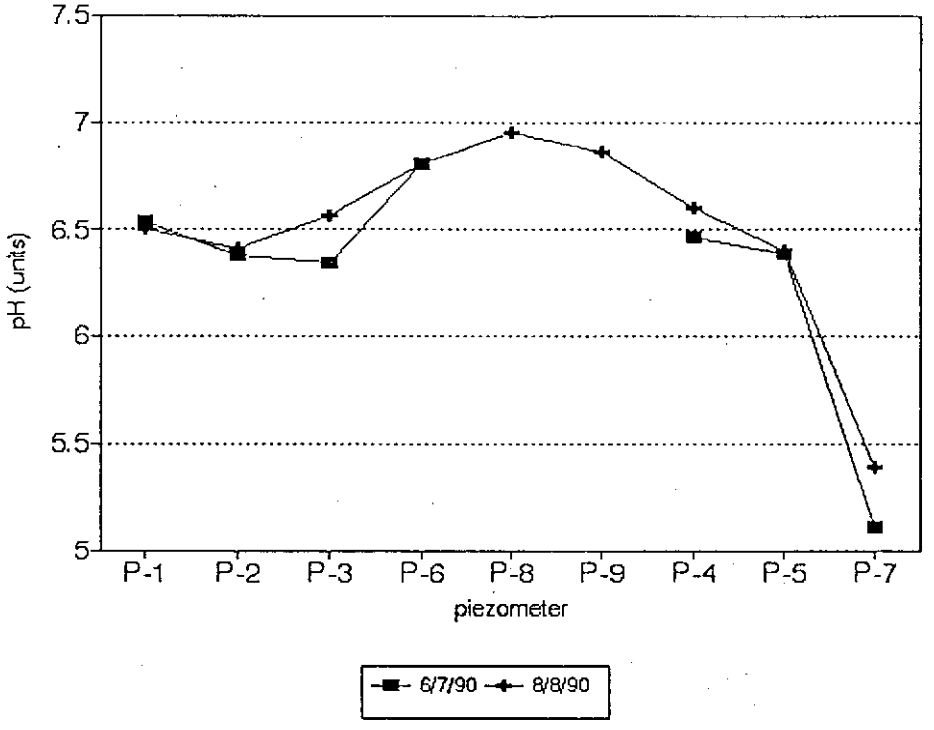


FIGURE 59: pH in Piezometers, 1990

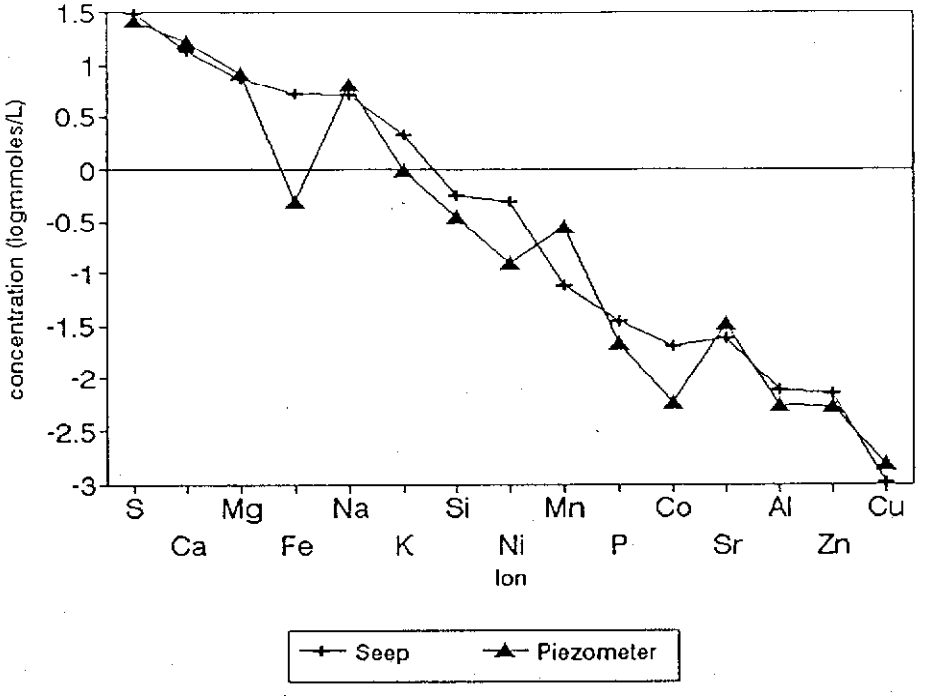


FIGURE 60: Average Ionic Concentration in Seep and Piezometers

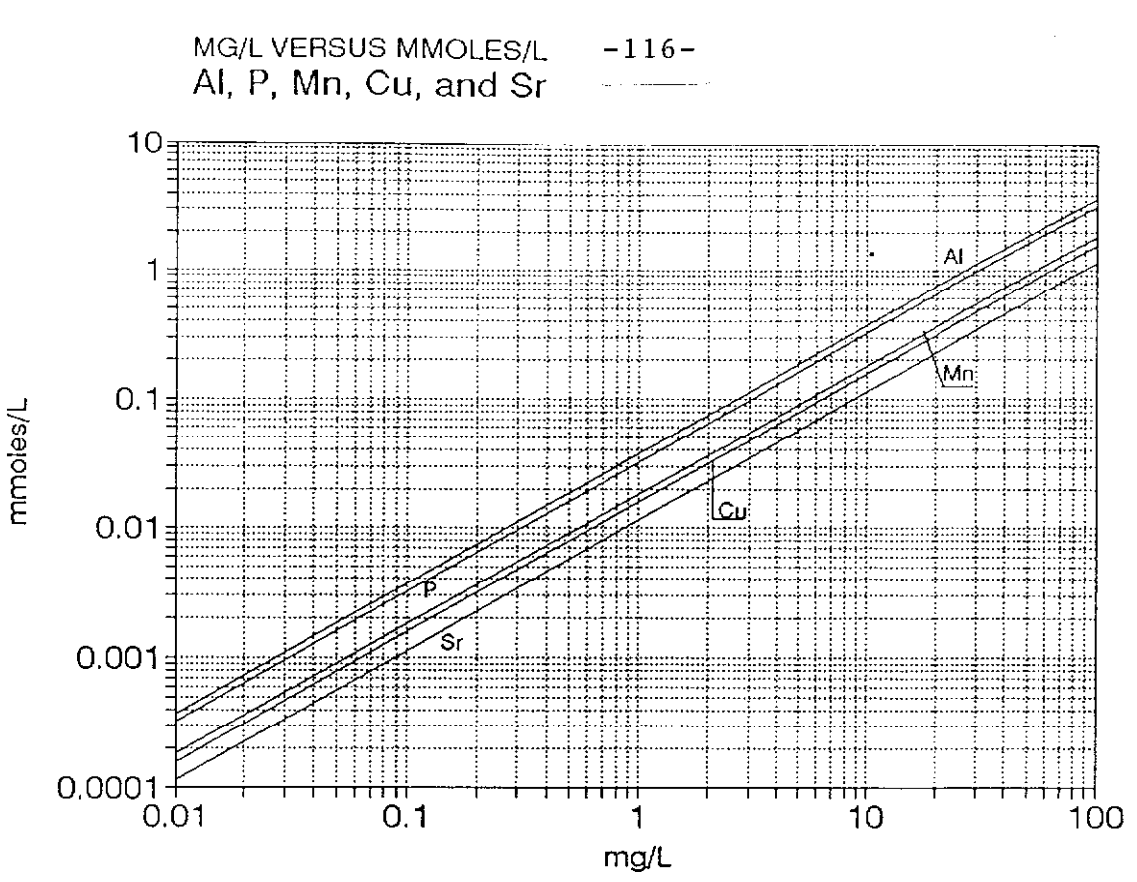


FIGURE 61a: mg/L Versus mmoles/L, Al, P, Mn, Cu, and Sr

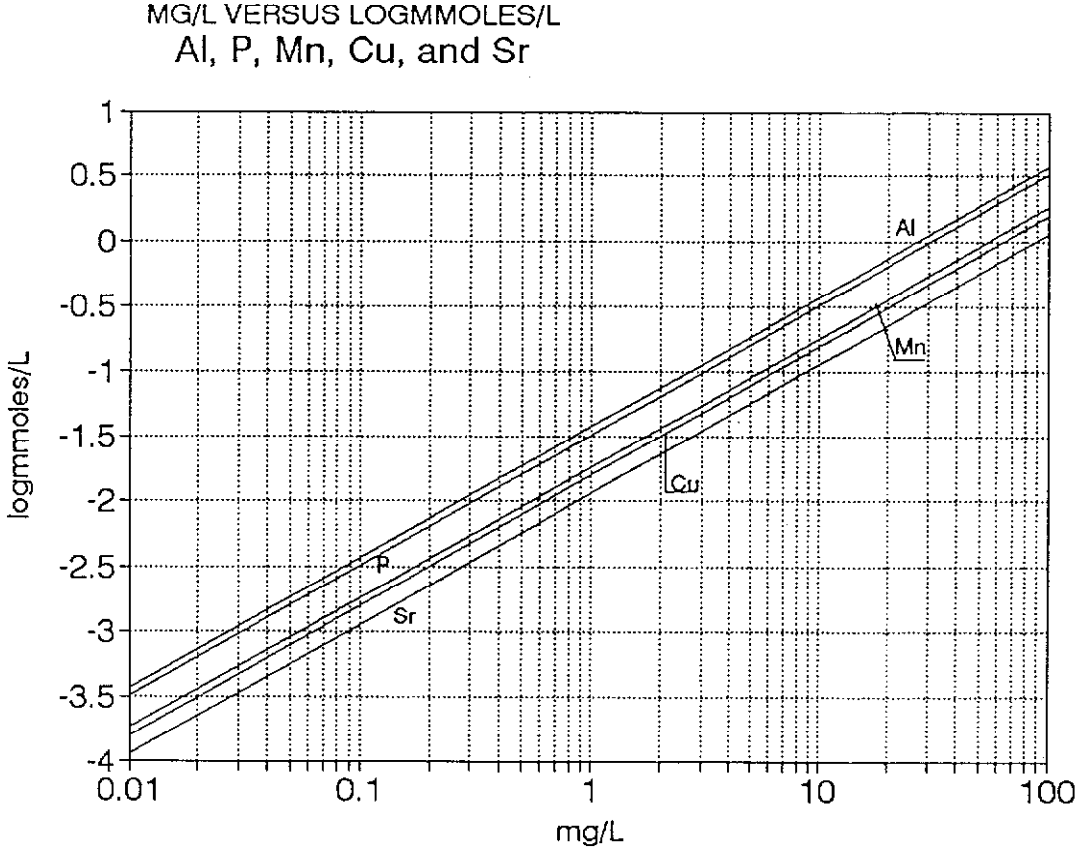


FIGURE 61b: mg/L Versus Logmmoles/L, Al, P, Mn, Cu, and Sr

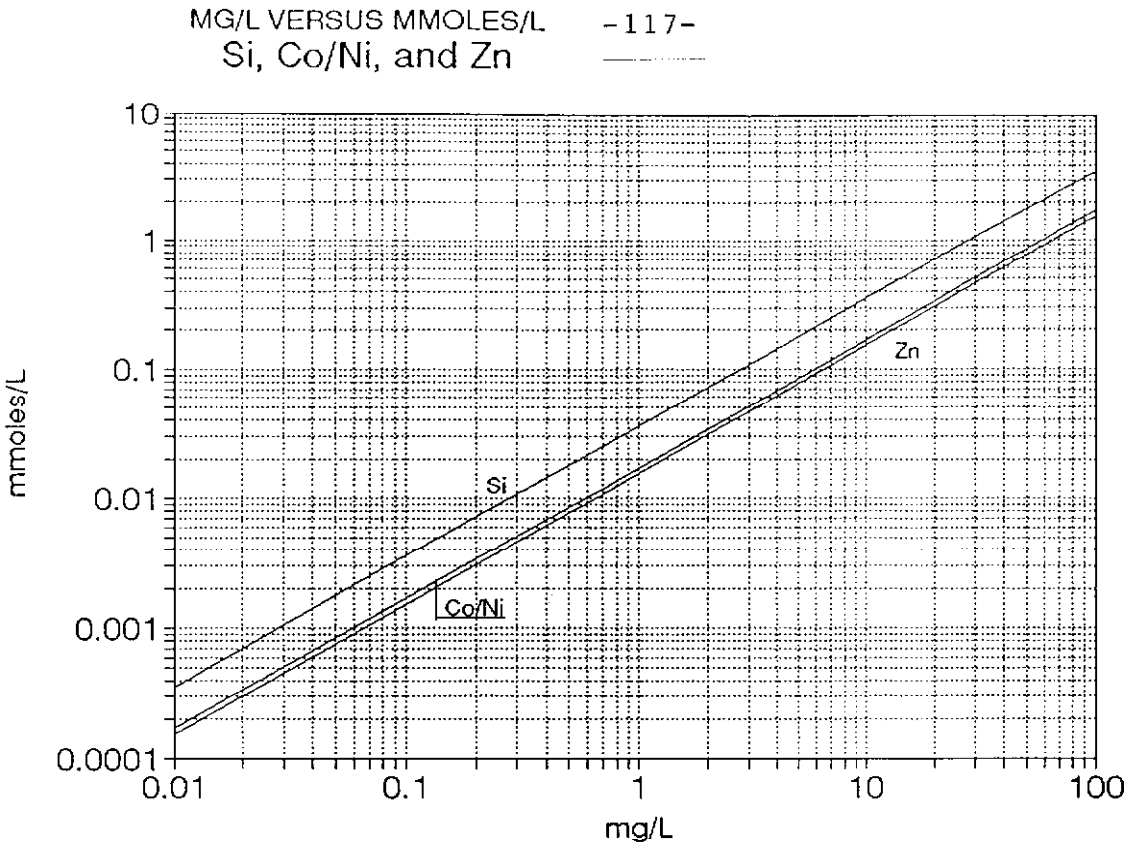


FIGURE 62a: mg/L Versus mmoles/L, Si, Co/Ni, and Zn

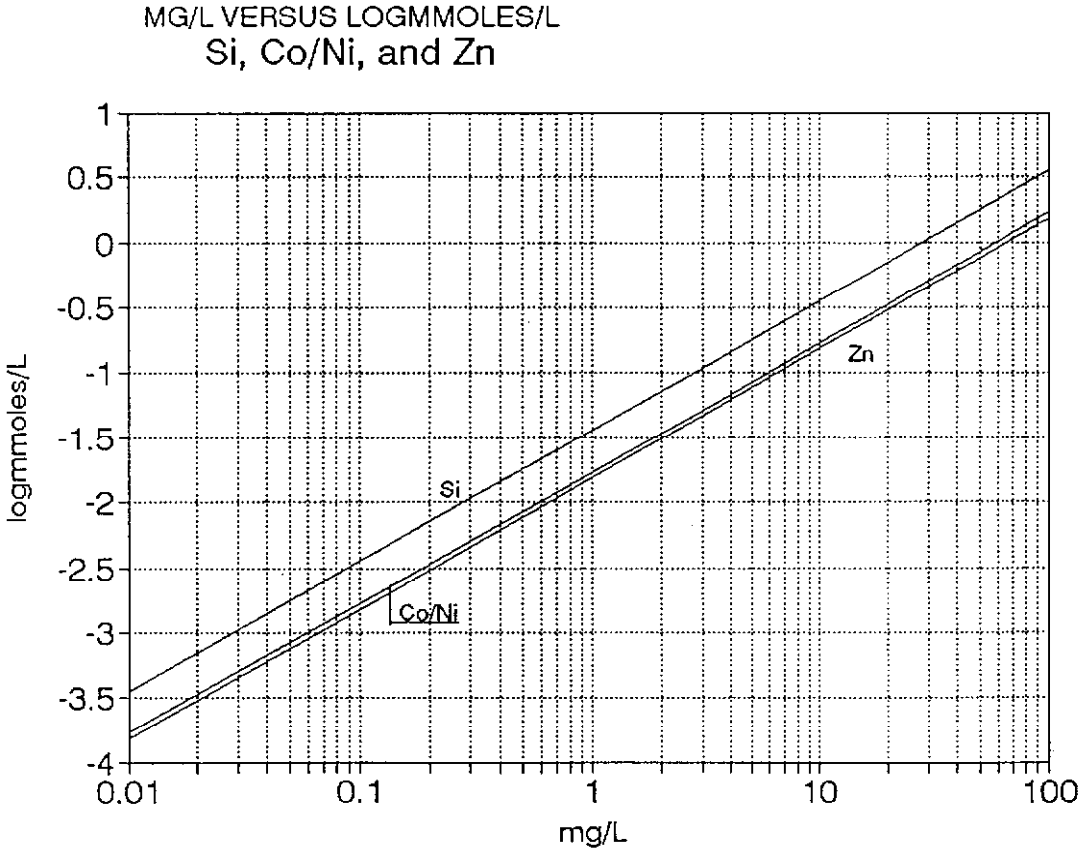


FIGURE 62b: mg/L Versus Logmmoles/L, Si, Co/Ni, and Zn

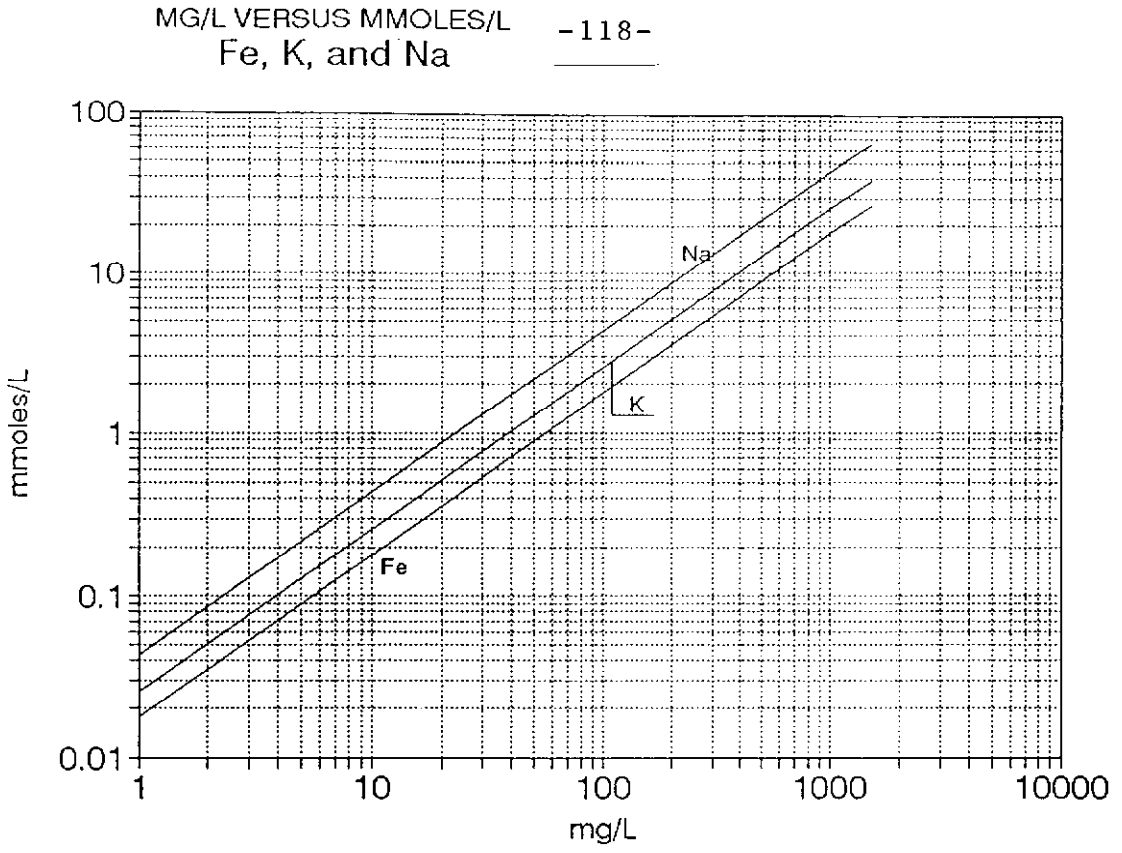


FIGURE 63a: mg/L Versus mmoles/L, Fe, K, and Na

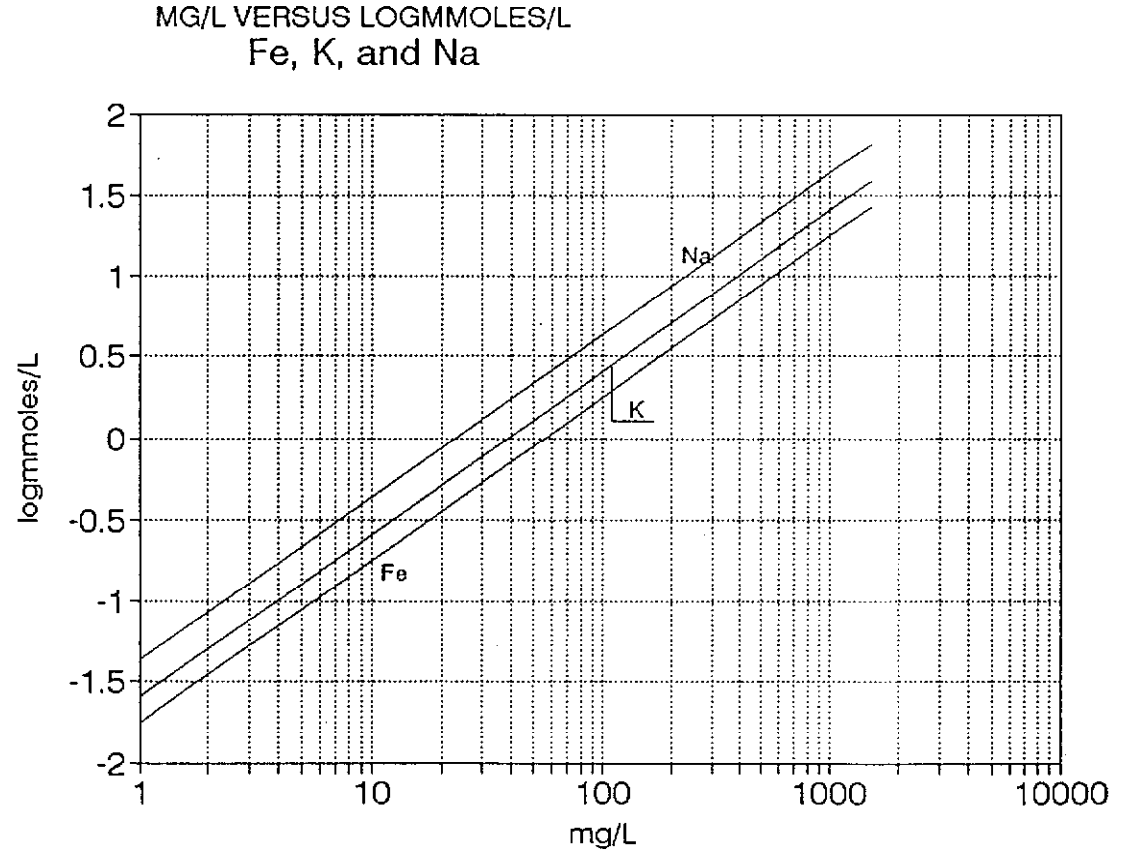


FIGURE 63b: mg/L Versus Logmmoles/L, Fe, K, and Na

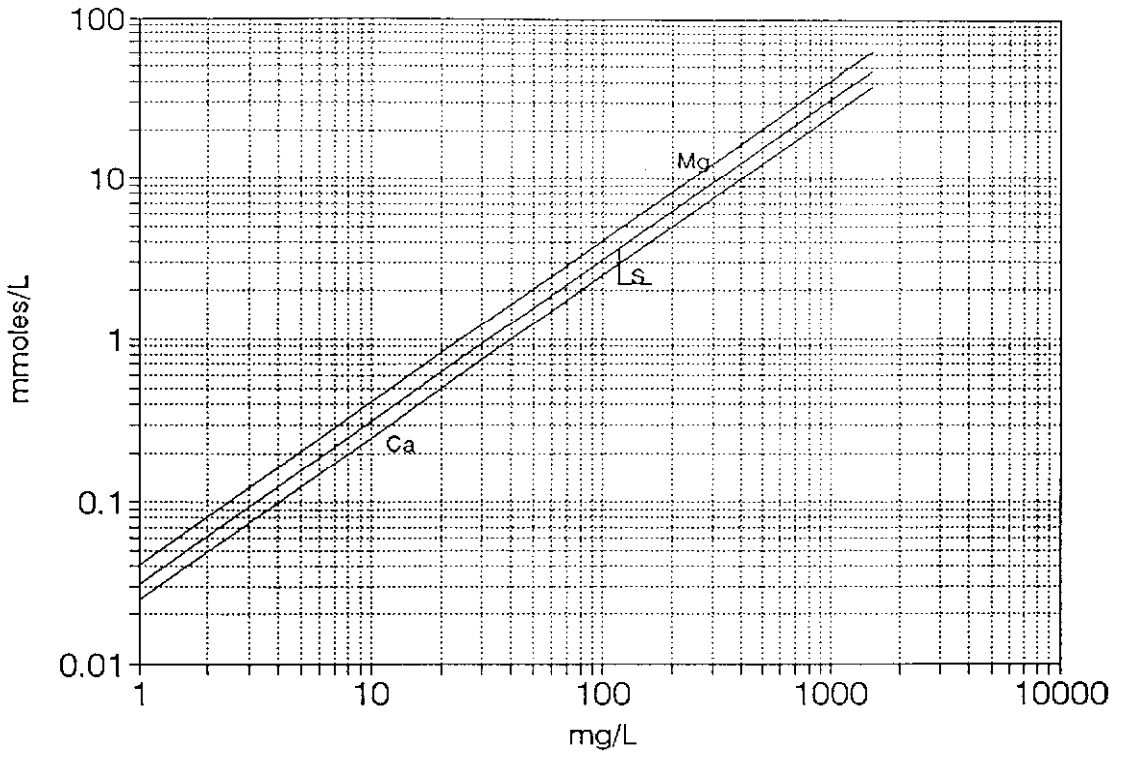


FIGURE 64a: mg/L Versus mmoles/L, Ca, Mg, and S

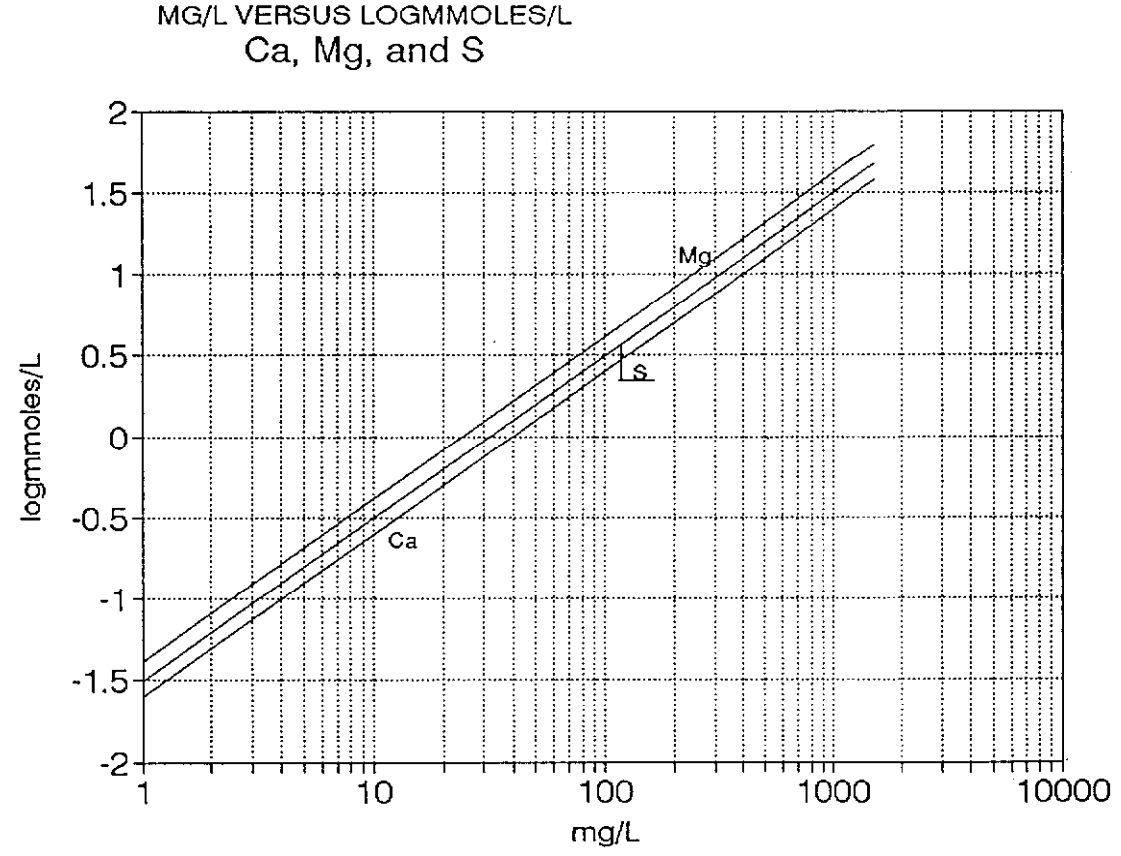


FIGURE 64b: mg/L Versus Logmmoles/L, Ca, Mg, and S

flask No.	sample removed on April 12	April 14				June 20 - 23C						June 20 - 8C				
		flakes	floc	plating	solution/ colour	flakes/ colour	floc/ colour	plating	solution	algae	colour	flakes/ colour	floc/ colour	plating	solution	colour
3	Denison - 1	no	little	no	milky	lt rusty	no	lt yellow	clear	no	dk yellow	no	no	yellow	clear	lt brown
2	Straw Pond 2	no	yes	no	clear	some	a few	lt yellow	clear	no	dk yellow	no	no	yellow	clear	lt brown
23	3	yes	no	no	milky	no	grey/rusty	dk yellow	clear	yes	dk yellow	no	brown precip	yellow	clear	lt brown
7	4	no	yes	no	milky	brown	grey/yellow	dk yellow	clear	no	lt brown	no	brown precip	milky	clear	lt brown
20	5	no	yes	no	dk brown	some	grey/yellow	yellow	clear	yes	lt brown	no	lt yellow, fungus	lt yellow	clear	lt rusty
1	flax	no	lots	no	milky-brown	some	grey/dk green	algae	clear	no	brown	no	lt brown, fungus	no	clear	brown
21	PBAC 1	lots	little	yes	milky	lt yellow	no	yellow	clear	no	flint	no	no	dk yellow	clear	lt yellow
16	2	yes	no	no	milky	no	milky yellow	yellow	clear	no	flint	no	lt yellow	dk yellow	clear	lt yellow
19	3	yes	yes	no	milky	no	yellow precip	yellow	clear	no	flint	no	fine orange precip	rusty	clear	lt brown
18	4	yes	yes	slight	milky	no	rusty	lt rusty	clear	no	lt yellow	no	brown, fungus	lt brown	clear	lt brown
14	5	yes	no	yes	milky	yellow	no	yellow	clear	no	flint	no	lt rusty	lt rusty	clear	lt yellow
15	6	yes	yes	yes	flint	no	yellow precip	yellow	clear	no	flint	no	no	lt amber	clear	lt yellow
5	Prebog 81	slight	slight	no	flint	lt yellow	grey/dk yello	algae	clear	no	flint	no	fungus only.	no	clear	lt yellow
22	Levack flax	little	yes	no	milky	no	milky brown	algae	clear	yes	lt brown	no	white precip, fungus	grey	clear	dk brown
12	Devco 2	no	yes	no	flint	no	brown	algae	milky	no	lt yellow	no	lt brown, fungus	no	clear	lt yellow
9	3	yes	yes	no	milky	no	dk rusty	lt brown	clear	no	lt yellow	no	lt brown	lt brown	clear	flint
4	4B	yes	no	no	flint	no	lt rusty	algae	clear	yes	flint	dk brown	little lt brown	no	clear	flint
6	6	yes	yes	yes	milky	little	dk yellow	brown	clear	no	flint	no	some yellow precip	dk yellow	clear	flint
17	Makela 2	no	slight	no	little milky	no	dk yellow	dk yellow	clear	yes	lt yellow	no	little yellow	lt yellow	clear	yellow
10	3	yes	no	no	milky	no	little	algae	clear	yes	lt yellow	no	fine	lt yellow	clear	lt yellow
13	4	no	yes	no	flint	no	little	algae	milky	yes	lt yellow	no	little milky	no	clear	flint
11	5A	no	yes	no	milky	dk rusty	lt brown	no	clear	yes	flint	no	little lt brown	lt yellow	clear	lt yellow
8	flax	no	yes	no	milky	no	milky brown	brown	clear	no	lt brown	no	little brown	no	clear	yellow

ARUM EXPERIMENTS: ARUM Jar Water Observations

FLASK	SAMPLE		4/12	4/13	4/14		4/16		4/19		4/24		4/26	
					room	fridge	room	fridge	room	fridge	room	fridge	room	fridge
			pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH
3	DENISON S.P.	1	2.13	2.12	2.12	2.19	2.16	2.15	2.21	2.45	2.23	2.50	2.36	2.69
2		2	2.14	2.13	2.13	2.21	2.20	2.11	2.20	2.38	2.24	2.50	2.32	2.65
23		3	2.19	2.16	2.19	2.25	2.29	2.22	2.19	2.50	2.27	2.69	2.38	2.74
7		4	2.13	2.10	2.09	2.19	2.05	2.08	2.22	2.39	2.35	2.64	2.38	2.70
20		5	2.04	2.04	2.04	2.15	2.12	2.09	2.12	2.33	2.27	2.40	2.30	2.50
1		flax	1.85	1.85	1.85	1.98	1.87	1.81	1.93	2.05	2.12	2.15	2.18	2.30
21	PBAC	1	2.84	2.78	2.73	2.55	2.50	2.39	2.25	2.67	2.33	2.80	2.40	2.82
16		2	2.84	2.78	2.85	2.88	2.51	2.65	2.23	2.69	2.33	2.78	2.42	2.82
19		3	4.55	3.80	3.21	3.30	2.63	3.08	2.34	3.18	2.43	2.70	2.38	3.05
18		4	5.00	4.93	4.75	4.81	2.94	4.07	2.52	4.02	2.74	3.87	2.73	3.74
14		5	3.05	2.98	2.79	3.09	2.49	2.70	2.30	2.71	2.36	2.80	2.40	2.84
15		6	3.67	3.58	3.01	3.18	2.65	2.82	2.37	2.82	2.32	2.80	2.38	2.90
5	PREBOG B1		2.58	2.56	2.52	2.52	2.47	2.48	2.43	2.63	2.61	2.79	2.70	2.80
22	LEVACK	flax	2.75	2.67	2.67	2.72	2.69	2.67	2.64	2.72	2.90	2.91	3.04	2.92
12	DEVCO	2	6.12	5.33	4.23	5.67	5.01	3.64	4.00	3.85	4.41	4.20	4.61	4.05
9		3	6.40	6.68	6.58	6.48	6.93	6.78	7.69	6.11	8.31	7.91	8.00	8.01
4		4B	5.23	3.74	3.69	3.73	3.88	3.61	3.70	3.73	3.58	3.65	3.70	3.60
6		6	3.91	3.00	2.72	3.09	2.48	2.80	2.33	2.84	2.59	2.80	2.62	2.85
17	MAKELA	2	7.67	8.03	7.53	7.98	7.93	7.49	6.94	6.93	6.65	7.40	6.60	7.78
10		3	7.51	8.02	7.99	7.58	8.04	7.58	8.61	7.49	8.80	8.40	8.60	8.30
13		4	7.34	7.20	7.80	7.95	8.35	7.40	8.69	8.60	8.19	7.90	8.40	8.30
11		5A	7.49	7.42	8.06	8.21	8.53	7.75	8.23	8.41	8.62	8.30	8.58	8.30
8		flax	7.23	7.60	7.86	7.92	8.20	7.86	8.25	8.25	8.25	8.20	8.20	8.30

ARUM EXPERIMENTS: ARUM Jar Water pH's (1 of 3)

FLASK	SAMPLE		5/01		5/02		5/05		5/07		5/09		5/11	
			room pH	fridge pH	room pH	fridge pH	room pH	fridge pH	room pH	fridge pH	room pH	fridge pH	room pH	fridge pH
3	DENISON S.P.	1	2.32	2.60	2.30	2.77	2.11	2.55	2.13	2.54	2.14	2.68	2.13	2.63
2		2	2.31	2.58	2.31	2.71	2.11	2.59	2.12	2.63	2.13	2.69	2.12	2.65
23		3	2.31	2.69	2.35	2.72	2.17	2.62	2.20	2.69	2.19	2.73	2.19	2.72
7		4	2.34	2.65	2.36	2.81	2.19	2.69	2.19	2.72	2.17	2.76	2.17	2.76
20		5	2.36	2.83	2.37	2.58	2.20	2.52	2.23	2.66	2.21	2.67	2.21	2.66
1		flax	2.27	2.20	2.25	2.31	2.11	2.27	2.15	2.38	2.10	2.34	2.09	2.37
21	PBAC	1	2.41	2.75	2.36	2.79	2.21	2.73	2.23	2.83	2.20	2.84	2.19	2.83
16		2	2.38	2.80	2.39	2.76	2.24	2.70	2.25	2.79	2.22	2.65	2.20	2.77
19		3	2.45	2.91	2.48	3.03	2.34	2.92	2.36	2.95	2.36	2.81	2.34	2.93
18		4	2.74	3.61	2.78	3.32	2.58	3.13	2.61	3.13	2.72	3.11	2.71	3.18
14		5	2.38	2.90	2.39	2.77	2.21	2.64	2.26	2.75	2.22	2.67	2.20	2.78
15		6	2.38	2.70	2.37	2.80	2.20	2.67	2.23	2.74	2.17	2.67	2.15	2.76
5	PREBOG B1		2.71	2.90	2.74	2.84	2.52	2.79	2.56	2.86	2.65	2.92	2.65	2.99
22	LEVACK	flax	3.11	2.80	3.15	2.96	2.71	2.90	2.61	2.97	2.66	3.03	2.64	3.11
12	DEVCO	2	4.30	4.10	4.14	3.85	4.05	3.68	4.32	3.84	4.37	3.99	4.27	3.98
9		3	8.50	8.10	8.64	8.01	8.53	7.83	8.10	7.74	8.29	8.00	8.51	8.03
4		4B	3.85	3.58	4.03	3.77	3.82	3.72	3.79	3.74	4.05	3.96	4.06	3.98
6		6	2.60	2.75	2.73	2.89	2.43	2.85	2.54	2.90	2.59	3.05	2.59	3.06
17	MAKELA	2	8.20	7.90	8.43	8.27	8.18	8.15	7.71	8.00	7.80	8.21	8.07	8.26
10		3	8.70	8.50	9.05	8.44	8.80	8.23	8.67	8.12	8.87	8.30	8.90	8.39
13		4	8.56	8.64	9.13	8.40	8.81	8.19	8.60	7.95	9.10	8.28	8.96	8.38
11		5A	8.70	8.25	8.95	8.43	8.70	8.29	8.53	8.10	8.76	8.34	8.79	8.40
8		flax	8.32	8.43	8.72	8.53	8.47	8.40	8.27	8.30	8.45	8.40	8.48	8.20

ARUM EXPERIMENTS: ARUM Jar Water pH's (2 of 3)

FLASK	SAMPLE		5/18		5/25		6/01		6/08		6/15	
			room pH	fridge pH	room pH	fridge pH	room pH	fridge pH	room pH	fridge pH	room pH	fridge pH
3	DENISON S.P.	1	2.00	2.44	1.90	2.20	2.05	2.48	2.10	2.55	1.99	2.36
2		2	2.00	2.54	1.91	2.23	2.03	2.59	2.10	2.65	2.03	2.47
23		3	2.07	2.53	2.05	2.16	2.11	2.62	2.17	2.69	2.09	2.47
7		4	2.04	2.50	2.00	2.13	2.09	2.60	2.15	2.65	2.07	2.40
20		5	2.09	2.48	2.04	2.11	2.13	2.58	2.13	2.67	2.03	2.43
1		flax	1.98	2.23	1.98	1.95	2.06	2.34	2.13	2.49	2.07	2.24
21	PBAC	1	2.02	2.62	2.04	2.28	2.08	2.60	2.17	2.70	2.11	2.48
16		2	2.03	2.54	2.03	2.28	2.08	2.63	2.16	2.69	2.11	2.46
19		3	2.20	2.65	2.20	2.33	2.22	2.68	2.27	2.82	2.22	2.48
18		4	2.56	2.92	2.54	2.49	2.62	2.99	2.68	3.05	2.56	2.70
14		5	2.02	2.51	2.07	2.22	2.08	2.61	2.14	2.72	2.16	2.45
15		6	1.96	2.48	2.00	2.24	2.04	2.57	2.07	2.71	2.06	2.43
5	PREBOG B1		2.47	2.77	2.42	2.38	2.53	2.86	2.57	2.90	2.46	2.60
22	LEVACK	flax	2.47	2.89	2.46	2.55	2.55	3.00	2.58	3.08	2.50	2.79
12	DEVCO	2	3.91	3.79	3.57	3.55	3.76	3.84	3.68	3.82	3.53	3.62
9		3	8.69	8.05	8.69	8.00	8.75	8.32	8.68	8.24	8.35	8.00
4		4B	3.86	3.74	3.67	3.47	3.91	3.81	3.91	3.88	3.86	3.61
6		6	2.42	2.78	2.41	2.38	2.48	2.84	2.52	2.94	2.48	2.65
17	MAKELA	2	8.21	8.32	8.24	8.06	8.20	8.20	8.46	8.28	8.36	8.10
10		3	9.49	8.52	9.09	7.99	9.09	8.36	9.07	8.43	8.86	8.23
13		4	9.00	8.28	9.04	8.04	8.97	8.39	8.91	8.33	8.75	8.15
11		5A	9.14	8.53	9.06	8.13	9.20	8.40	9.03	8.43	8.66	8.22
8		flax	8.62	8.30	8.45	7.77	8.58	8.34	8.55	8.40	8.42	8.22

ARUM EXPERIMENTS: ARUM Jar Water pH's (3 of 3)

APPENDIX 2

METHODS

NOTES ON REDOX MEASUREMENTS

E, Eh, Em, and pE

Standard Potential: E

Chemical reactions in which a participating element changes valence number, losing or gaining orbital electrons, are referred to as oxidations or reductions, respectively. The reduction process can be represented by an expression such as

$$Fe^{3+} + 2e^{-} = Fe^{2+}$$

where ferric iron is reduced to the ferrous state. The expression represents a "half-reaction" or redox couple. A reduction does require a source of electrons; this could be another element which is simultaneously oxidized, or an actual source of electric current.

Under standard conditions (25°C and 1 atm.) and with unit activity of the reactants, a certain electrical potential would be present in such a redox couple. This "standard potential" is conventionally represented by the symbol E, given in volts, with the potential of the hydrogen electrode taken as zero.

The sign of the potential associated with a half-reaction written as a reduction is negative if the system is reducing, and positive if the system is oxidizing. The magnitude of the value is a measure of the oxidizing or reducing tendency of the system.

Redox Potential: Eh

When the activities of participating species in a system differ from unity, the potential observed at equilibrium is termed the "redox potential", represented by the symbol Eh. It is directly related to the standard potential and to the ratio of the activities of the participating oxidized and reduced substances.

Measured Potential: Em

If an inert metal electrode (commonly platinum) is immersed in a solution containing oxidized and reduced species, it should attain an electrical potential matching that of the redox couples in the system - assuming that a reversible equilibrium exists among electron-donating and electron-accepting species and the electrode surface. The size and sign of the potential can be evaluated if a "standard electrode" (e.g. calomel electrode), having a known

potential, is also immersed in the solution, and both electrodes are connected to a sensitive electrometer. Most pH meters have provision for such measurements.

If the temperature T of the aqueous system differs from the standard temperature of 25°C, the measured "electrode potential" Em should be corrected at least for temperature effects on the potential of the standard electrode. For the standard calomel electrode the correction can be represented by

$$Eh(millivolts) = Em(millivolts) + (241 - 0.66 * (T - 25)$$

Activity of Electrons: pE

Another form of expressing redox potential has been used widely in recent geochemical literature. Basically, this nomenclature writes electrochemical potentials in terms of the negative base - 10 logs of "activities of electrons" per litre, represented by the symbol pE. Under standard conditions (25°C and 1 atm.), when Eh is given in volts,

$$pE = Eh / 0.0592$$

and when Eh is given in millivolts

$$pE = Eh / 59.2$$

The use of pE in this way simplifies calculations that use redox equilibria along with other types of reactions (e.g. in the geochemical simulation code PHREEQE). It is used primarily in the general field of aqueous environmental chemistry. Thermodynamic implications of the concept of "activity of aqueous electrons" have not been fully explored. Electrons may of course be transferred between aqueous ions or between aqueous ions and a solid-surface component during chemical reactions, but they do not exist independently in the solution, and they can have no activity there in the sense that the participating solutes do.

Ranges of Eh and pE

Eh values for normal oxygenated waters with pH values between 6.0 and 8.0 range generally from +0.35 to +0.55 volt (pE from +5.912 to +9.291). The maximum possible range allowed by the stability limits of water at pH 7.0 is from -0.42 to +0.82 volt (pE from -7.095 to +13.85).

MICROBIAL METHODS

All chemicals, media and nutrient supplies were obtained from the sources described in the April, 1990 progress report except where indicated.

Most analytical methods also were described in this progress report. Any new methods are described in the sections below.

1.1 Field ARUMators

The 45 gallon ARUMators were fabricated out of used plastic drums (water softener for boilers) which were thoroughly washed. On site they were allowed to stand with AMD seepage water for 1 h which was discarded. Sampling ports were installed inside the drum using ABS pipe (1.5 in. diam.). Five iron rods (rebar; 0.5 in.; 2 ft lengths) were placed in the ARUMators. Iron enhanced microbial populations in the lab tests described above. The rebar for all 5 Arumators was purchased from the same batch. The ARUMators were filled with the organic amendment mixtures, small rocks and AMD seepage water.

1.2 Makela Flow Experiments

Three water column reactors had been prepared as described in April 1990 Progress Report (Section 2.10). Three experiments were conducted using these reactors. Acidic water samped from the same Makela site was used in these experiments.

2.1 Makela Flow Experiment I

Acidic seepage water continued to be pumped into column reactor #3 at the intermittent rate of 2.1 mL every 30 minutes or approximately 100 mL per day and an equal volume simultaneously removed. This process continued until the pH decreased to 4.0. (Most of the alkalinity required to raise the pH to 4.0 occurs during this phase). Sulphate, nickel and iron concentrations continued to be monitored.

1.2.2 Makela Flow Experiment II

In the following experiment acidic seepage water was pumped into water column reactor #2 at an intermittent rate of 2.1 mL every 30 minutes or approximately 100 mL per day, and an equal volume was simultaneously removed.

The flow configuration was changed to emulate more closely field conditions, influent or acidic seepage was pumped into the middle port of the reactor and effluent was collected at the top of the water level. This process continued until pH decreased to below 4.

Samples obtained from the top, middle and bottom ports of the reactor were analyzed for the presence of microbiological groups including iron reducing bacteria, sulphate reducing bacteria, ammonifying bacteria and denitrifying bacteria.

1.2.3 Makela Flow Experiment III

The purpose of this experiment was to determine whether reactors previously exposed to excessive flow rates could recover and regenerate sufficient alkalinity to neutralize acidic seepage to above pH 4 under flow conditions.

Acidic seepage water was pumped into two water column reactors at an intermittent rate of 2.1 mL every 30 minutes or approximately 100 mL/day. The process continued until the pH decreased to below 4.0.

1.3 Denison Flow Experiments

The test amendments were added to three water column reactors. The order of addition to each reactor was gravel followed by amendment and acidic seepage water from the Denison seepage site.

The amendment portion consisted of a 1 cm layer of iron filings covered by a flax layer which filled two thirds of the reactor (ie. to a level of 1.5 L). Denison acidic seepage was then added to cover the amendment. The reactors then received 10 mL of a microbial seed from the Buchans Oriental East limnocorral site which contained sulphate reducing bacteria.

The acidic seepage water was allowed to stand at ambient temperature (22° C) for at least 24 h prior to addition to the reactors. The reactors were incubated at ambient temperature (22° C) and were observed for blackening indicating the presence of sulphate reducing bacteria. After 2 weeks and weekly thereafter, pH was determined.

1.3.1 Denison Flow Experiment I

Once blackening was observed and the pH became >5, acidic seepage water (allowed to stand at ambient temperature (22° C)) was pumped into two reactors (#1 and #3) at an intermittent rate of 2.1 mL every 30 minutes or approximately 100 mL/day and an equal volume was simultaneously removed. This process continued until pH decreased to below 4.0.

Microbiological profiles were performed on samples obtained from Denison reactor #1 and #3 prior to flow.

Measurements of sulphate, nitrate, sulphide and total soluble carbohydrates were also determined prior to flow.

1.3.2 Denison Flow Experiment II

In this experiment, the acidic seepage water was pumped into a "recovered" reactor (which generated sufficient alkalinity to neutralize the acidic seepage to above pH 5) at an intermittent rate of 2.1 mL every 30 minutes or approximately 100 mL/day. Acidic seepage was pumped into the middle port of the reactor and effluent was collected at the top of the water level. This process continued until pH decreased to below 4 (reactor was unable to maintain ARUM process).

In addition to pH, the influent and effluent were monitored for changes in sulphate, volatile fatty acids and total soluble carbohydrates.

A microbiological profile was performed on a sample obtained from the bottom port of the water column reactor.

1.4 Evaluation of Algae as an ARUM Amendment

This experiment examined the potential of algae to initiate alkalinity. Amendment test conditions were set up in 40 mL Wheaton vials. The order of addition was gravel (2 cm), amendment (1.0 cm) then acidic seepage water.

The treatments tested were as follows:

(i) algae (2 cm) and 2 mL seed;
(ii) 2 cm finely ground flax (ground in a Waring blender for 60 seconds) and 2 mL of seed.

The vial containing algae was covered with aluminum foil.

The seed was obtained from a sawdust amendment sample taken from the Oriental East limnocorral of the Buchans mine site, in Newfoundland. The vials were incubated at ambient temperature and observed for blackening. pH was also monitored.

1.5 Denison Acidic Seepage: Useful Forms of Iron for Process Initiation

A series of 40 mL Wheaton vials were prepared to determine whether rusted iron would be successful in the initiation of alkalinity.

The order of addition to the vials were gravel, amendment and Denison acidic seepage water supplemented with BOD mineral nutrients at the concentration applied for a standard BOD test (Standard Methods, 1985).

The treatments were as follows:

(i) flax and 2 mm of iron filings;
(ii) flax and rusted iron filings;
(iii) flax and 10 de-greased rusted iron finishing nails.

The vials were incubated at ambient temperature and were observed for blackening.

1.6 Treatment of Denison Mine Seepage: Amendment Screening

An assortment of treatments were utilized to determine whether successful alkalinity generation could be achieved.

The order of addition to 40 mL Wheaton vials was gravel, amendment and acidic seepage water. The treatments were as follows:

(i) flax;
(ii) flax and iron filings and 1 mL of seed;
(iii) flax, 1 mL seed and 200 ppm of $Ca(NO_3)_2$;
(iv) flax, 1 mL seed and 400 ppm $NaNO_3$;
(v) flax, 1 mL of seed and 500 ppm Na_2SO_3.

The flax was ground for 60 seconds in a Waring blender prior to addition.

Acidic acid seepage was allowed to stand at ambient temperature (22° C) for at least 24 h prior to its addition.

Mineral nutrients used for BOD analyses, as described in Standard Methods for the examination of Water and Wastewater 16th edition were added to the vials.

The seed was obtained from the Buchans Oriental East limnocorral site which was known to contain sulphate reducing bacteria.

The vials were incubated at ambient temperature. After a few weeks, pH was determined. The vials were further observed for blackening indicating the presence of sulphate reducing bacteria.

1.7 Denison Acid Seepage: Contribution of Iron and Amendment to Alkalinity

A number of test conditions were set up to determine whether the test amendment itself contributed to alkalinity generation.

A set of 40 mL Wheaton vials were set up. The order of addition was gravel, amendment and acidic seepage. The treatments were as follows:

(i) flax and iron filings;
(ii) flax;
(iii) iron filings.

The amendment/water vials were sterilized by a Tyndalization Method (Brock, Smith, and Madigan, 1984). The vials were incubated at 80° C for 10 minutes. This procedure is repeated three times over several days. The pH was monitored prior to heat shock, and following first and third heat shock.

1.8 Denison Alkalinity Generation Mechanism: Determination of Microbiological Group Capable of Independently Initiating Alkalinity

Forty mL Wheaton vials were prepared to determine which microbiological groups were capable of initiating alkalinity generation.

The order of addition of amendment to the vials were 2 cm gravel, 2 cm finely ground flax, 2mm iron filings and Denison acidic seepage. The vials were then sterilized by the Tyndalization Method as described in Section 1.6.

After the final heat shock, pH-adjusted (pH 2.2) filter sterilized sodium lactate (3 g/L) was added to the vials which would be inoculated with sulphate reducing bacteria and iron reducing bacteria. Sodium lactate was added since it was necessary for the growth of these bacteria. The sodium lactate was also filter sterilized to ensure that only sulphate reducing bacteria or iron reducing bacteria were present in the test environment.

The vials to be inoculated with ammonifiers did not receive sodium lactate since the carbon source necessary for their growth was present in the vial. The vials were then inoculated with pure cultures of sulphate reducing bacteria, iron reducing bacteria and ammonifier bacteria (see Section 2.8 and 2.9 respectively).

The sulphate reducing bacterial cultures and ammonifier cultures were obtained from a sample from the middle port of Denison water column reactor #3. The iron reducing bacterial culture was obtained from a sample from the middle port of Makela water column reactor #3.

The pH of the vials before and 3 weeks following bacterial inoculation was determined.

1.9 Mechanisms of Alkalinity Generation: Isolation of Pure Cultures of Sulphate Reducing Bacteria

Samples were taken from the top, middle and bottom port of Denison and Makela water column reactors. The samples were inoculated into Postgate B media and incubated at 28° C for 3 weeks. The vials were observed for blackening indicating the presence of sulphate reducing bacteria.

Positive cultures were re-inoculated into Postgate B media and incubated at 28° C for a further 3 weeks.

Postgate E medium was then prepared and cooled to 44.5° C. While molten, oxyrase (30 units/mL) was added to the media. The media was then poured into petri dishes and 1 mL samples of SRB cultures and then dilutions were added. The samples were then incubated in anaerobic pouches (Difco) at 28° C and observed for blackening.

After a 3 week incubation period, blackened colonies appeared. Postgate B media was then inoculated with positive colonies and incubated at 28° C for 3 weeks. The cultures are presently being maintained.

1.10 Mechanisms of Alkalinity Generation: Isolation of Pure Cultures of Iron Reducing Bacteria and Ammonifiers

Samples were taken from the top, middle and bottom port of Denison and Makela water column reactors and inoculated into IRB and ammonifier media. The samples were incubated at 28° C for 3 weeks. Samples from positive tubes were plated on TGE agar and incubated at 28° C. Colonies were picked and re-inoculated into IRB and ammonifier media for positive confirmation. These cultures are presently being maintained.

1.11 Determination of Organic Acids

During anaerobic digestion of organic wastes, significant concentrations of volatile fatty acids are formed. They are the carbon sources for a variety of organisms including SRB's and IRB's.

Organic acid concentrations were determined by a colorimetric chemical method using ferric hydroxamate (Thomas and Chamberlain, 1974). Organic acids react with hydroxylamine to produce hydroxamic acid. The colour of the complex formed by reaction of the hydroxamic acids with ferric chloride is a measure of hydroxamic acid concentrations and thus of the original organic acid concentration. The colour reaction was measured by a spectrophotometric method (505 nm) relative to reference organic acid standards. Acetic acid was used as the standard. Prior to analysis, samples were neutralized and filtered through 0.2 micron filter unit.

1.12 Preparation of Volatile Fatty Acid Producer Media

Volatile fatty acid (VFA) producer media was a modification of a medium (Hutkins and Kashket, 1986) for the growth of Clostridium acetobutylicum (a species capable of producing volatile fatty acids from glucose) with the addition of 100 ppm sodium molybdate ($Na_2MoO_4.H_2O$).

After autoclaving, the media was cooled and oxyrase (enzyme which removes oxygen) was added (30 units/mL). The media was dispensed aseptically into sterile 15 mL serum vials containing a layer of sawdust and then capped.

Sodium molybdate inhibits the growth of sulphate reducing bacteria and iron reducing bacteria which would otherwise use the organic acids produced in the media. Sawdust was added as a substrate for organisms that are able to produce volatile fatty acids directly from cellulose.

At the end of the incubation period tests for volatile fatty acids were conducted as described in Section 2.10, using uninoculated media as the blank. The tests are usually conducted qualitatively.

1.13 Comparison of Sulphate Reducing Bacteria Enumeration Methods

Comparison of the Rapidchek® Sulphate Reducing Bacteria Detection System (Conoco Specialty Products Inc., Houston, Texas) versus conventional cultural test media were made. The assay is based on the fact that all sulphate reducing bacteria possess the enzyme APS reductase. The Rapidchek® SRB Detection System uses purified antibodies specific to this enzyme to detect the presence of sulphate reducing bacteria.

Various ARUM water and amendment samples were analyzed for the presence of sulphate reducing bacteria. The water samples were filtered through 25 micron nitex screen and tested. The amendment samples were prepared in tap water. The vials were shaken and liquid was filtered though 25 micron nitex screen prior to analyses. In addition, 1 mL aliquots of each sample were inoculated into Postgate B media and serial dilutions were made.

1.14 Amendment Decomposition in the Field

1.14.1 Denison

Amendment pouches were placed in the field on July 17, 1990. All amendments (Sawdust, Alfalfa, Straw, Cattails and Peat) were assembled at Straw Pond. Pouched fabricated from window screen fabric were fabricated to retain the weighed amendments. It is intended to expose the amendment materials to the effluent water for specific periods of time. Following retrieval the amendment will be dried and checked for weight loss and analyzed for cellulose content and ICP. Subsequent exposure times can be decided according to the information generated from the initial exposure.

1kg, 3kg or 5kg of amendment material was placed in the pouches. Samples of the original material placed have been retained for moisture, ICP and cellulose content. Each pouch has been labelled denoting the site location, material used, weight placed and anticipated exposure time.

In addition, a time capsule has been placed in each pouch containing a label denoting the same information as above. This will protect the information if the pouches have to be left in the test area for longer than anticipated, or over winter.

The location of the experiment is in Straw Pond upstream of the Straw Dam. The depth of the pond was not sufficient to suspend the pouches in free water. Therefore the pouches were placed on a strip of snow fencing and placed on the bottom of the pond. The

pouches were weighed down with wooden planks to ensure that the pouch contents would remain under water. Marker floats were placed at each corner of the snow fencing to outline the location of the experiment.

1.14.2 Makela

Amendment pouches were constructed at Makela and placed in the test cells on July 18, 1990. The same experimental procedure was used at makela as at Deison Straw Pond. The materials used at Makela were the same as at Denison with the exception of sawdust type. Fine grain sawdust was used at Denison which contains fine particulates which may be flushed from the pouch. This would be a source of error due to weight loss other than through decomposition. At Makela wood shavings with less fine particulates were used to reduce this potential error.

The location of the experiment is in the constructed test cells. The 1kg and 3kg pouches have been placed in test cell 3, and the 5kg pouches has been placed in test cell 4.

Placement of the pouches was again on snowfencing, but as the depth of water was sufficient, the pouches were suspended in free water. The pouches were attached to the fencing with the plastic ties and the fencing was weighed down under the water level.

1.15 Cellulose Decomposition

The cellulytic capability of the cellulose degrading population was determined by testing the capability of the microorganisms to degrade cellophane stained by Remazol brilliant blue (Moore, Basset, and Swift, 1979).

Nylon screen bags containing Remazol Brilliant Blue (RBB) stained cellophane strips were placed in the top and bottom level of Makela Reactor #2. After a time period of 12 months the bags were removed and analyzed for the percent of cellulose decomposition. This was determined by measuring the stain relative to reference RBB stained cellophane strips taken from the same dye batch as the test strips.

1.16 Sequential Nutritional Analyses of Amendment

Sequential nutritional analyses of amendment following a 12 month ARUM operation in Makela acidic seepage water was performed.

A simplified version of the forage fibre analysis method (Goering and Van Soest, 1970) was used which involved a series of extraction steps.

Initially, the amendment was extracted with acetone which removed lipids and resins. This was followed by an hydrochloric acid (HCI) reflux step which removed soluble sugars, starch, amino acids, and hemicelluloses. Finally, a sulphuric acid digestion was performed on the amendment which removed the remaining cellulose. The

samples were dried at 40° C over night and weighed between each extraction step. The percent loss from each treatment was determined.

1.17 Metabolic Activity in ARUM Water Column Reactors as Measured by Carbon Dioxide and Methane

ARUM water column reactors were analyzed for the production of methane and carbon dioxide (CO_2). Following flushing of the reactor headspace CO_2 metabolic activity was determined. Both CO_2 and methane in the samples were measured by gas chromatography.

DESCRIPTION OF EVOLUTION OF FLOW CONTROL

During and after spring break-up (March/April, 1990) considerable flow under and around the weirs was noticed. SUbsequestly, during early May, 1990, the weirs were replaced with 4" pipes, equipped with valves. At this time, the erosion blankets were also removed. Shortly afterwards, May 15, 1990, amendment dams were placed in Cell 4. Further adjustments to the flow control were made during the first half of June. from June 20 to July 8, 1990 the flow through the system was regulated to 40L/min. Subsequestly, the flow was reduced to 4-5 L/min (july 10, 1990). At this time additional amendment dams were also placed in Cell 3 (July 9, 1990). Unfortunately, partial plugging by straw of the outflow from Cell 4 occurred between July 10 - 18, 1990. This caused the water level in cell 3, pond B, and cell 4 to rise. This resulted in partially drowned amendment dams in cell 4 and total drowning in cell 3. To compensate for the reduced outflow from cell 4, the valve between cell 2 and pond A was throttled back to 3 L/min (June 19,1990). On August 8, 1990 it was found that the outflow from cell 4 had dropped to < 1 L/min, which, in turn, had resulted in a further rise in the water levels in cell 3, pond B, and cell 4. The amendment dams in both cell 3 and 4 were now totally drowned. Remedial action was taken and the flow was again regulated to 5 L/min.

A summary of the water levels in the cells and ponds, and the corresponding outflow rates from the system is presented in Figure 6. The effect of the outflow rate on the water levels in the cell system is evident.

METHODS OF PRECIPITATE SEDIMENTATION

Upon arrival in the laboratory the samples were allowed to settle in graduated cylinders for a minimum of 16 hrs prior to further processing. After this period the amount of slurry was measured and the supernatant water decanted. This water was saved for settlement tests conducted on the slurry. The slurry was subsequently homogenized and an aliquot of 40 ml was taken. This aliquot was mixed with the previously saved water from the same sample to a ratio of: total volume (slurry + water)/ volume slurry = 5 / 1. A 250 ml graduated cylinder was used for the determination of the settling behavior of this mixture.

The settling experiments were standardized after it was found that the settling behavior of a slurry is not only dependent on the ratio between the total volume and the volume of the slurry, but also on the size of the graduated cylinder used for the determination.

DETAILED WATER CHEMISTRY ANALYSIS ON CELL 4:

The results of the August 24, 1990 water samples for the bottom of cell 4 and station 14 illustrates major differences between the two water samples. Iron shows a considerable increase, while metal ions such as Ni, Co, Al, Zn, and Cu show significant decreases (Figure 48b). If these data are superimposed on the results obtained in water samples collected on August 8, 1990 for station 14 (24/8) the water has essentially the identical in composition to station 14 (8/8) and no evidence of mixing with groundwater can be found. Cell 4 "bottom" shows higher concentrations of Fe and Mn and lower concentrations of Al and Cu as compared to the cell outflow and the groundwater. On the other hand the concentration of K, Si, Co, Ni, and Zn in the cell 4 "bottom" water could readily be derived from mixing of groundwater and cell 4 water. The Eh of the cell "bottom" water is 60 mv.